Australian Government
Department of Defence
Defence Science and Technology Organisation

Modification of the Geographic Corrosivity Index and its Application to Overseas Bases

J. C. Bitcon and S. G. Russo

Maritime Platforms Division
Defence Science and Technology Organisation

DSTO-TR-2109

ABSTRACT

A Geographic Corrosivity Index (GCI) has been developed previously that models the atmospheric corrosivity at RAAF bases within Australia. Geographic, wind and other climate data are used to calculate the index for each base. The correlation of the GCI with atmospheric corrosion data from a large number of overseas bases, covering a broader range of geographic features and climatic conditions than experienced in Australia, was investigated to test its wider application. Modifications have been made to the GCI that enable it to be used with greater confidence for bases around the world that are within 200 km of the coast. Bases greater than 200 km from the coast have low corrosion rates, and a simpler algorithm based on time of wetness and distance from the coast has been used to predict atmospheric corrosivity at these inland sites.

Published by

Maritime Platforms Division
DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

AR-014-150
March 2008

APPROVED FOR PUBLIC RELEASE

Modification of the Geographic Corrosivity Index and its Application to Overseas Bases

Executive Summary

A Geographic Corrosivity Index had been developed previously that predicts the average annual environmental corrosivity at bases and airports within Australia and at some overseas sites. Development of the index enabled prediction of monthly variations in corrosivity as well as average annual corrosivity (Geographic Corrosivity Index Annual or GCIA) at Australian bases with considerable success. Weight loss results from Al/Cu CLIMAT specimens were used as the measure of corrosivity. The GCIA is an empirical model that uses ratings based on geographic information and various average annual climate data:

- Distance of site from the coast
- Average fetch at the coast nearest the site, where fetch is the distance of sea over which the wind blows before reaching land
- Strength of the wind blowing from the two directions likely to carry the most sea generated salt aerosol to the site, i.e. off-sea winds
- Time of wetness at the site, calculated from temperature and relative humidity.

To increase confidence in the application of the index to a wider range of geographic and climatic conditions, the correlation between the GCIA and weight loss data from aluminium alloy coupons exposed in the open at 38 sites in the US, Europe, Asia and the Pacific and Indian Ocean regions was investigated.

Initially the correlation was only moderate. Modifications were made to the GCIA that improved the correlation considerably for sites within 200 km of the coast:

- Greater weight was given to sites near the coast
- More wind directions were considered
- Fetch was associated with each individual wind direction

A simpler algorithm was devised that predicted the corrosivity for sites more than 200 km from the coast, using time of wetness and distance of the base from the coast.

These algorithms have been used to predict a Location Index (LI) for each of the overseas sites of interest to the Tactical Fighter Systems Progam Office. The LI is a measure of the environmental corrosivity of a particular site, and is used to calculate a cumulative Corrosion Index (CI), which tallies the severity of environmental exposure of an aircraft on a daily and continuing basis. The CI is a useful tool for planning aircraft washing and maintenance schedules to optimise fleet availability and life.

Authors

J.C. Bitcon
Maritime Platforms Division

Jim Bitcon is a contract senior engineer in the Corrosion Control Group of the Marine Platforms Division. He graduated with a Bachelor of Engineering (Metallugy) from the University of Melbourne, and then worked at the National Physical Laboratory, Teddington, UK for seven years during which time he was awarded a PhD by the University of Surrey.

On returning to Australia he worked in the copper and aluminium alloy extrusion industry for many years in areas such as R & D, failure analysis, corrosion testing, manufacturing processes and quality systems. At DSTO he is working on several corrosion mitigation projects for TFSPO at RAAF Williamtown.

S.G. Russo
Maritime Platforms Division

Stephen Russo graduated with a Bachelor of Engineering (Materials) from Monash University. He is currently undertaking part-time graduate studies towards a Masters in Systems Engineering at RMIT University.

Upon graduation he commenced work at DSTO and has gained considerable knowledge and experience on corrosion damage of aircraft alloys. In particular, he has been involved in various collaborative programs both within Australia and overseas investigating atmospheric corrosivity and the impact of corrosion on fatigue crack growth. He is currently involved in gaining a better understanding of the factors that influence corrosion of aircraft materials and the use of various system engineering processes to manage the RAAF fleet.

Contents

1. Introduction

The Geographic Corrosivity Index (GCI) had been developed [1, 2] to predict the environmental corrosivity at bases, both in Australia and overseas. It used readily available climate and geographic data to model average weight loss from aluminium-on-copper-bolt CLIMAT "Classification of Industrial and Maritime Atmospheres Test" (Al/Cu CLIMAT) test specimens [3] exposed at various sites. Weight loss from the aluminium wire on the CLIMAT specimens, expressed as a percentage, was used as the measure of environmental corrosivity.

The original GCI [1] predicted the average environmental corrosivity at bases using average annual climate data. The index was then developed further [2], using average monthly climate data, to predict monthly variations in corrosivity at Australian bases with a reasonably high degree of accuracy (Geographic Corrosivity Index Monthly or GCIM). The developed index could also be used to predict average annual corrosivity (Geographic Corrosivity Index Annual or GCIA). However, the GCIA and GCIM have been developed largely from data from Australian bases and conditions, although data from some Canadian and New Zealand (NZ) bases and airports, and one United States (US) site, were also used in the original work. To increase confidence in the application of the GCIA to overseas sites, the correlation between the GCIA and weight loss data obtained by Battelle Columbus Laboratories [4, 5, 6] for aluminium alloy coupons exposed in the open at 38 sites was investigated. These sites were in the US, Europe, the United Kingdom, Asia and the Pacific and Indian Ocean regions.

This report outlines the problem of poor correlation encountered when the GCIA is applied to the Battelle results, and the modifications made to the GCIA that markedly improve the correlation for sites within 200 km of the coast. The modified GCIA is then correlated with the original average CLIMAT results from Australia, Canada, NZ and the US. This CLIMAT correlation is used to predict the average CLIMAT results for the overseas bases and airports of interest to the Tactical Fighter Systems Program Office (TFSPO) that are within 200 km of the coast. A simpler algorithm is developed to predict CLIMAT results for sites further than 200 km from the coast, where corrosivity is low. These CLIMAT predictions are then used to establish a Location Index (LI) that can be used to calculate a Cumulative Corrosion Index (CI) [2].

2. Modification of the GCI

2.1 Brief review of development of the GCI

The original GCI algorithm [1] had a very strong linear correlation (R^2 = 0.966, where R is the linear correlation coefficient) with the average Al/Cu CLIMAT results for 12 Australian, eight Canadian, two New Zealand and one US sites. The algorithm involved ratings for distance to the coast, geography of the coast, average wind speed and time of wetness (TOW).

A modified algorithm, GCIM, was developed to model the monthly variations in Al/Cu CLIMAT results at the 12 Australian bases [2]. These modifications involved slight changes to the distance to the coast and coast ratings, and the substitution of a wind aggregate incorporating wind direction and wind speed ranges instead of average wind speed. This algorithm, the GCIA, when applied on an average annual basis, gave a slightly improved correlation (R^2 = 0.978) with the average Al/Cu CLIMAT results for the 12 Australian bases when compared to the original GCI. The GCIA is described by the following equation:

$$GCIA = DR*GR*WA^{0.26}*TR^{0.38} \tag{1}$$

where DR = Distance Rating
GR = Geographic Rating
WA = Wind Aggregate
TR = TOW Rating

Values of the ratings are given in Table 1 under "Original GCIA Ratings". Modified GCIA ratings are also given in Table 1, and these are discussed later.

2.2 Application of the GCIA to Battelle corrosion weight loss data

Although the GCIA exhibited a very strong correlation with the Al/Cu CLIMAT results for the 12 Australian bases studied, the algorithm needed to be tested against overseas corrosion rate data before it could be applied with confidence to overseas sites generally.

CLIMAT data was available for only a limited number of overseas sites (those used in the original GCI work), but large amounts of weight loss data were available from studies performed by Battelle Columbus Laboratories for the US Air Force, and reported by Kinzie [4, 5, 6], covering many air bases and airports in the US, Asia, Europe and Pacific and Indian Oceans with a wide variety of climatic and geographic characteristics. The weight loss data was obtained on coupons of aluminium alloys 6061 and 7075 exposed in the open.

Comprehensive climate data for most of the exposure sites were obtained from the National Oceanic and Atmospheric Administration (NOAA) [7], with annual average operating time for each wind direction and wind speed range, and annual average atmospheric temperature and relative humidity, being available from measurements at three hourly intervals throughout the years. The NOAA data were averages obtained over at least nine years during the period 1980 – 1996, but in most cases the data covered several decades, in some instances going back to the 1940s. For a few sites a full set of NOAA climate data was not available. In these cases climate data from a nearby weather station, if available, were used.

Table 1 Original and modified GCIA algorithm ratings

Original GCIA Ratings	Modified GCIA Ratings
Distance Ratings (DR): 5 < 1 km 4 1 - 3 km 3 > 3 - 10 km 2 > 10 - 60 km 1 > 60 km	**Distance Ratings (DR):** 9 0 – 0.3 km 8 > 0.3 – 0.7 km 7 > 0.7 – 1.2 km 6 > 1.2 – 1.8 km 5 > 1.8 – 2.8 km 4 > 2.8 – 8.0 km 3 > 8.0 – 15.0 km 2 > 15.0 – 60.0 km 1 > 60 – 120 km 0.5 > 120 – 200 km 0.3 > 200 – 300 km 0.1 > 300 – 1000 km 0 > 1000 km
Wind Aggregate (WA): Time (%) during month that the 3 pm wind blows from the two directions likely to deposit the most salt aerosol at the base being considered (weighted for wind speed) – see Appendix A.	**Wind Aggregate (WA):** Time (%) during the year that the wind blows from those of the eight ordinal directions where there is < 1000 km to the sea at the base being considered (weighted for wind speed) – see Appendix A.
Geographic Ratings (GR): 6 Island: exposed to open sea. 4 Open Sea: > 120° with a clear distance > 100 km. 3 Restricted: bays, gulfs, off-shore islands, etc. 40° - 120° with a clear distance > 100 km. 2 Reef: off-shore reef within 100 km. 1 Sheltered: inlet, narrow strait, etc. < 40° with a clear distance > 100 km. 1 > 60 km inland from coast.	**Fetch Ratings (FR):** 0 If fetch < 2.5 km, or if fetch 2.5 - 25 km unless distance to sea < or = 2 km. 5 Reef: off-shore reef or rocks within 5 km. 5 2.5 – 5 km fetch. 10 > 5 – 10 km fetch. 12 > 10 – 40 km fetch. 14 > 40 – 100 km fetch. 16 > 100 - 300km fetch. 18 > 300 – 600 km fetch. 26 > 600 – 1000 km fetch. 32 > 1000 fetch.
Time of Wetness Ratings (TR): Annual TOW (h), calculated from average annual temperature and relative humidity data.	**Time of Wetness Ratings (TR):** Annual TOW (h), calculated from average annual temperature and relative humidity data.

These data were used in the current work as they gave a more accurate estimate of the conditions applying on a 24 hour basis, rather than the 3 pm wind rose data and the percent relative humidity calculated from morning and afternoon percentage relative humidity readings used previously. The NOAA wind data were given in two different formats, depending on the base. These formats, and the way they were used to calculate the wind aggregate, are described in Appendix A. As previously, an estimated value of TOW was calculated from a formula devised by Tidblad *et al.* [8], using annual average temperature and relative humidity.

The Battelle weight loss data for alloys 6061 and 7075 at the various sites, and the corresponding GCIA and associated data are given in Appendix B. The alloy 6061 results were used for this part of the work as there were 35 sites with alloy 6061 data compared to 24 sites with alloy 7075 data that had the required weather records. The relationship between the GCIA and the Battelle weight loss results for alloy 6061 are shown in Figure 1.

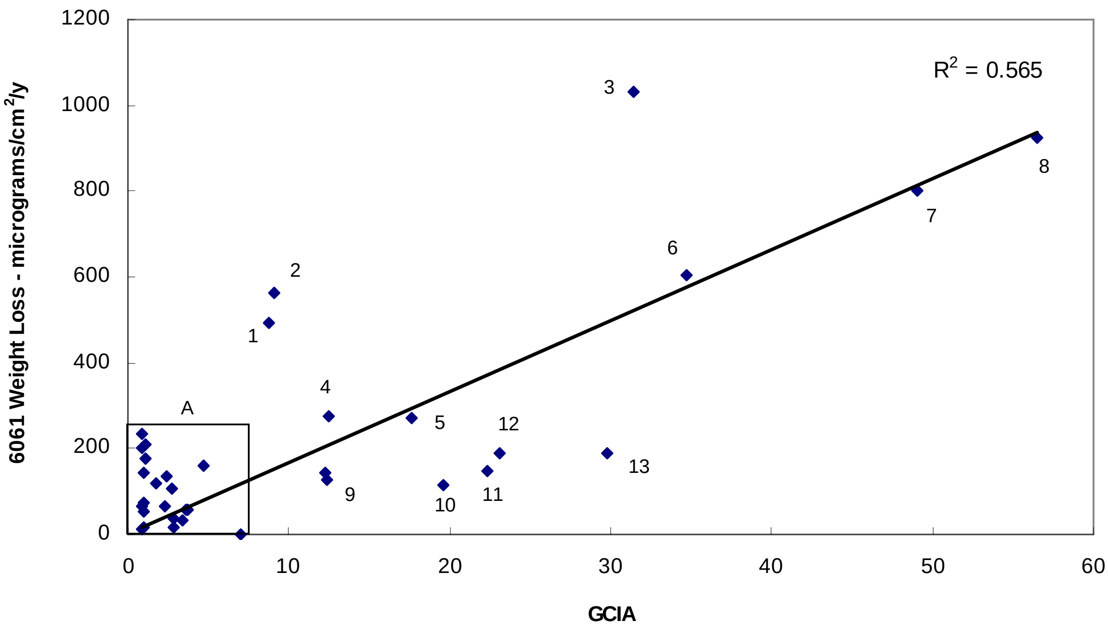

Figure 1. Relationship between GCIA and Battelle alloy 6061 weight loss data for 36 bases. All data points for bases more than 200 km from the coast are in area A. Numbered data points are individually identified in the text.

The linear correlation shown has been forced through zero, and is for the GCIA algorithm with the powers for WA and TOW optimised to produce the best correlation (R^2 = 0.565):

$$\mathrm{GCIA} = \mathrm{DR*GR*WA}^{0.63}\mathrm{*TR}^{-0.20} \qquad (2)$$

Note that the optimised power for TOW is -0.20, although the correlation is weak; if the TOW power in the algorithm is changed to +0.20, R^2 only drops to 0.557. The negative correlation with TOW, albeit a weak one, is a surprising result given that TOW is usually considered a driver of corrosion. This result may be due, in part, to uncertainties in the TOW values. The TOW values used here are estimates based on the time during the year that ambient conditions are both greater than 0°C and greater than 80% relative humidity [8], in accordance with the atmospheric corrosivity classification standard, ISO 9223 [9]. Uncertainties in these estimated TOW values arise from such factors as the imperfect nature of the algorithm used to calculate TOW (correlation coefficient between observed and predicted TOW was 0.89 [8]), the somewhat arbitrary setting of values of 0°C and 80% relative humidity (corrosion has been reported at temperatures less than 0°C [10] and mixed chlorides and other salts on sample surfaces are likely to deliquesce at less than 80% relative humidity [11]), and the absence of information on the samples and their exposure that could affect condensation and TOW (mass, orientation, wind, cloud cover, etc) [12].

The weak correlation with TOW may also be due, in part, to chloride on the aluminium surface dominating the corrosion process, which is likely to be pitting. Weak and/or negative correlations between TOW and weight loss on aluminium alloys exposed in the atmosphere have been reported by other workers [13, 14, 15].

Several observations were made from Figure 1:

a) All of the inland sites (> 200km from the coast) were clustered at the lower end of the GCIA range (within the area labelled "A" in Figure 1). When considered on their own, the inland sites exhibited a poor negative correlation with the GCIA (R^2 = 0.413). These inland sites are considered separately later in the report.

b) The correlation between weight loss and the GCIA when all sites were considered was poor (R^2 = 0.565). The correlation was slightly worse when only sites within 200 km of the coast were considered (R^2 = 0.531). Other observations below refer only to sites within 200 km of the coast.

c) Data points for Langley (1), MacDill (2) and Corpus Christi (3) were all considerably above the correlation line i.e. the weight losses were markedly greater than predicted by the GCIA. A common feature of these sites was that they were surrounded by sea or sea water on at least three sides, which would subject them to a higher risk of windborne sea-generated salt aerosol than less exposed sites.

d) Data points for Kadena (4), Hurlburt (5), Kunsan (6), Brindisi (7) and Shemya (8) were all close to the correlation line. These sites were all very close to the sea, i.e. within 4.1 km.

e) Data points for Pease (9), Atlantic City (10), Taipei (11), Daytona Beach Airport (12) and Guam (13) were all considerably below the correlation line. These sites, with the exception of Guam, were at moderate distances from the coast, i.e. 7 – 18 km. Guam is within 1.8 km of the coast but has off-shore reefs.

2.3 Modifications to the GCIA

The observations in Section 2.2 above highlighted several modifications to the GCIA that might improve the correlation with the Battelle alloy 6061 weight loss data. It was desirable that any modifications made to the GCIA to improve the correlation with the alloy 6061 weight loss data should not be detrimental to the correlation with Al/Cu CLIMAT results, and this was a criterion when investigating changes to ratings.

2.3.1 Distance Rating

Several Battelle sites were very close to the coast, as noted in d) above. These sites were generally within 2 km of the sea, but the current distance ratings do not adequately reflect the high chloride deposition rates observed at such sites [16, 17, 18]. Australian sites of interest are usually > 2 km from the sea and the current ratings, which were designed for Australian conditions, gave no detailed consideration to sites very close to the coast.

A considerably higher weighting on coastal sites seemed warranted and resulted, in association with other changes described below, in improvements to the correlation. Distance ratings were modified accordingly, as shown in Table 1 under "Modified GCIA Ratings". In addition, slight adjustments were made to ratings for distances > 60 km from the coast as these also lead to correlation improvements.

2.3.2 Wind Aggregate

Some of the Battelle sites were exposed to the sea or salt water on three sides, as noted in c) above. These sites exhibited higher weight losses than predicted by the GCIA. The wind aggregate in the GCIA only considered, from the eight main compass directions (N, NE, E, etc), the winds blowing from the two directions likely to deposit the most salt aerosol at the site being considered.

Logically, salt aerosol could be deposited by a wind coming from any direction provided it had previously blown over the sea and the aerosol has not been depleted by the wind subsequently travelling long distances over the land. The GCIA for the exposed sites would be increased considerably if more wind directions were included in the wind aggregate, and the correlation with weight loss probably improved. Work performed by Cole *et al.* [19] at the Commonwealth Scientific and Industrial Research Organisation indicated that salt aerosol may be transported at least 355 km inland by the wind. Improvement in the correlation between GCIA and alloy 6061 weight loss data was achieved by including all those winds in the wind aggregate where the sea was < 1000 km in the direction from which the wind was blowing.

The calculation of the wind aggregate, using increased weighting at higher wind speed ranges, is explained more fully in Appendix A.

2.3.3 Geographic Rating

One interpretation of the current geographic rating is that it gives an average rating for the fetch at the coast nearest the site being considered (see Table 1), the fetch being the distance of sea over which the wind blows before reaching land.

With more wind directions being included in the wind aggregate, a more comprehensive way of predicting the effect of the winds on salt aerosol at each site has been developed. For each wind direction, the distance to the coast and the fetch distance beyond the coast were used to assign a DR and a fetch rating (FR), these ratings being shown in Table 1. These ratings were combined with the WA for the particular wind direction to form a geographic factor (GF) for that wind direction:

$$GF = DR*FR*WA^n \qquad (3)$$

with the WA being raised to the power n, as in the previous algorithm. In those instances where two or more bodies of water were involved, e.g. the site may be in a bay with the open sea further away, DR and FR were established for each body of water and the highest DR*FR product was used.

The geographic rating (GR) for the site is the sum of the GFs for each valid wind direction, i.e. those wind directions for which DR and FR are not zero. For a given alloy, the power, n, is the same for all sites and wind directions, and is set so that the linear correlation coefficient between the modified GCIA and weight loss data is maximised. Using this GF approach also did away with the need to consider islands as a special geographic case.

As with the earlier index development, the results strongly suggested that the presence of off-shore reefs or rocks close to the coast caused a considerable reduction in aerosol production, possibly due to a decrease in the impact of surf hitting the shoreline. Setting the fetch rating to a value of five when reefs/rocks were within 5 km of the coast instead of using the normal fetch rating was found to considerably improve the correlation.

2.3.4 TOW Rating

The TR remain unchanged, except that the relative humidity used in the calculation of TOW was the average of three-hourly readings [7] instead of a value estimated from morning and afternoon relative humidity readings used previously [1].

2.3.5 Modified GCIA

The modified GCIA (ModGCIA) algorithm takes the following form:

$$\begin{aligned} \text{ModGCIA} &= TR^m*GR \\ &= TR^m*\Sigma(DR*FR*WA^n) \qquad (4) \end{aligned}$$

For a given alloy, the power, m, is the same for all sites, and is set so that the linear correlation coefficient between ModGCIA and weight loss data is maximised.

2.4 Application of ModGCIA to Battelle weight loss data for sites < 200km from the coast

ModGCIA data for each of the 20 sites within 200 km of the coast for which alloy 6061 weight loss data were available are given in Appendix C. The WA and TOW powers have been optimised to produce the best correlation between ModGCIA and alloy 6061 weight loss:

$$\text{ModGCIA} = TR^{-0.37} * \Sigma\,(DR*FR*WA^{0.41}) \qquad (5)$$

The relationship between ModGCIA and alloy 6061 weight loss is shown in Figure 2, with $R^2 = 0.770$. The correlation shown has been forced through zero.

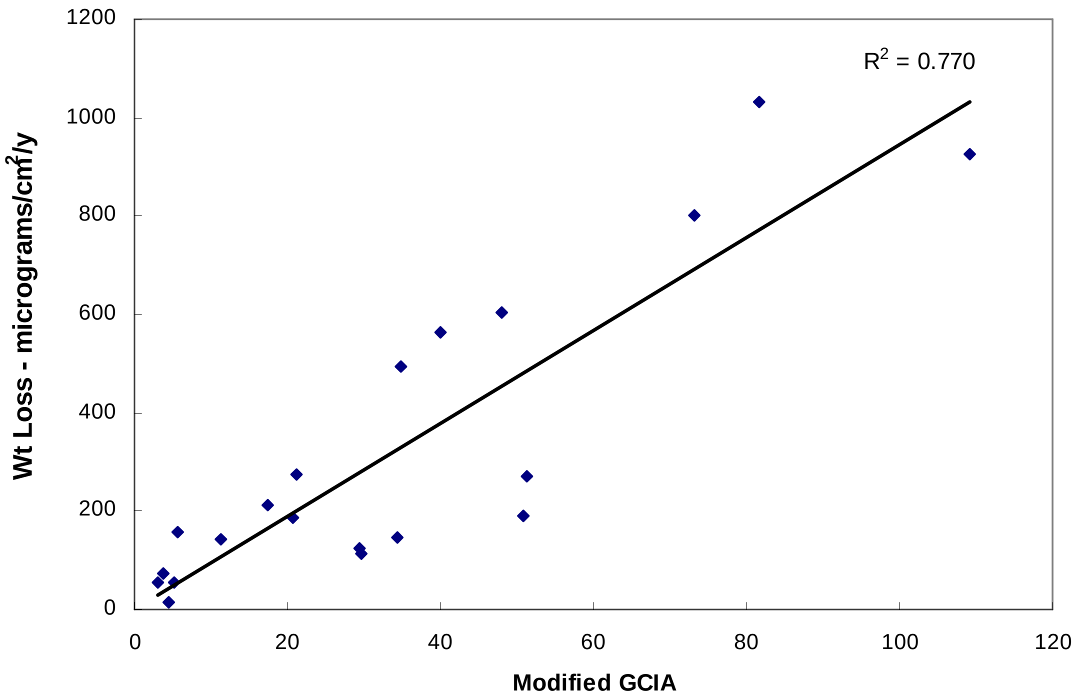

Figure 2. Relationship between the modified GCIA and Battelle alloy 6061 weight loss data for 20 bases within 200km of the coast.

A similar exercise on the alloy 7075 weight loss data gathered at 20 sites produced the following relationship:

$$\text{ModGCIA} = TR^{-0.52} * \Sigma\,(DR*FR*WA^{0.49}) \qquad (6)$$

The relationship between ModGCIA and alloy 7075 weight loss exhibited $R^2 = 0.581$. Both algorithms again exhibited a negative power for the TOW rating, and again the correlation of TOW with weight loss for both sets of results was weak; if the TOW powers in the algorithms were changed from negative to positive values, then R^2 only dropped slightly to 0.750 and 0.537 for alloys 6061 and 7075 respectively.

In general ModGCIA was considered to give reasonable to good correlations with alloy 6061 and 7075 weight loss data over a wide range of sites within 200 km of the coast, given that pitting is the main type of atmospheric corrosion occurring on aluminium. Pitting results in quite low weight loss values that are inherently more prone to variation. The modifications have substantially reduced the problems noted earlier for alloy 6061 regarding sites close to the coast and on exposed peninsulas.

2.5 Simple algorithm for modelling CLIMAT weight loss data for sites > 200 km from the coast

Weight loss data for sites > 200 km from the coast did not correlate well with GCIA. For example, the correlation with alloy 6061 weight loss exhibited a negative correlation with $R^2 = 0.413$. This was not surprising as wind data and coastal shape become less relevant to levels of ocean salt aerosol the further inland the site. Inland corrosion rates tend to be low, as shown by the alloy 6061 results where the sites > 200 km from the coast all exhibited weight loss values < 250 μg/cm^2/y.

A simple approach was taken to model inland sites. The algorithm for sites < 200 km from the coast can be viewed as a TOW factor combined with a chloride deposition rate factor estimated from wind data, coastal shape and distance from the coast. As wind data and coastal shape become less relevant at inland sites, distance from the coast can be considered the main determinant of chloride deposition rate. As chloride levels have been reported to fall over considerable distances inland from the coast [19], the correlation of corrosion rate with the ratio of TOW to distance from the coast was investigated.

Three inland sites were available with Al/Cu CLIMAT results, two Canadian [20] and one Australia [21], and these Al/Cu CLIMAT results were modelled directly. The Canadian sites (Trenton and Winnipeg) and the Australian site (Tindal) had seven and nine Al/Cu CLIMAT results respectively. Each result was for an approximate three month exposure, and the exposures were spread over a two year period for the Canadian sites and just over three years for the Australian site. The relevant data for each site is shown in Appendix D.

The individual results exhibit considerable variation, as expected, as temperature and relative humidity vary throughout the year at any site, which in turn produces variations in TOW. As the algorithm is designed to predict only the average yearly Al/Cu CLIMAT value, the individual Al/Cu CLIMAT results have been averaged to give an estimate of the annual atmospheric corrosivity. The average Al/Cu CLIMAT value exhibited a moderate correlation with the ratio of average TOW to distance from the coast ($R^2 = 0.795$), but the correlation was markedly improved when average TOW was raised to the power 0.49 (R^2 = 0.999), as shown in Figure 3.

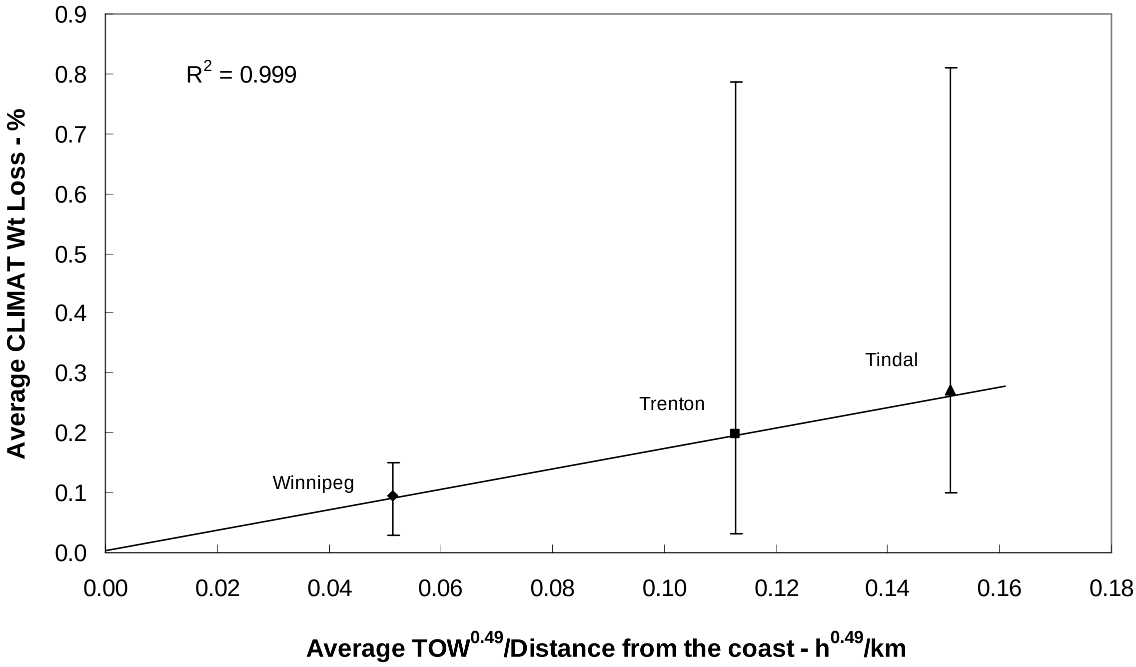

Figure 3. Relationship between average TOW$^{0.49}$/distance from the coast and average Al/Cu CLIMAT weight loss data for three sites > 200km from the coast. Individual Al/Cu CLIMAT range bars are shown for each site.

The correlation shown has been forced through zero, and is described by the following equation:

$$\text{CLIMAT} = 1.784 * \text{TOW}^{0.49} / \text{Distance from the coast} \tag{7}$$

Given the limitation of only three sites and the complex nature of corrosion, the almost perfect correlation is no doubt fortuitous. However, as the data points shown are the average of 7 - 9 individual results, and the three sites cover a variety of climatic and geographic conditions, it is considered reasonable to use the algorithm to predict the annual atmospheric corrosivity at inland sites for classification purposes.

3. Predicting Environmental Corrosivity

3.1 Correlation of ModGCIA with CLIMAT test data for sites < 200 km from the coast

The average weight loss from Al/Cu CLIMAT specimens is used as the measure of environmental corrosivity. Al/Cu CLIMAT and NOAA data were available for six Australian, five Canadian, three New Zealand and one US sites within 200 km of the coast [1], and these are given in Appendix E along with the corresponding ModGCIA data and ratings. The relationship between ModGCIA and the CLIMAT weight loss results is shown in Figure 4.

The correlation between ModGCIA and the CLIMAT results was excellent, with $R^2 = 0.986$, and is described by the following equation:

$$\text{Al/Cu CLIMAT} = 0.00382 * \text{ModGCIA} \qquad (8)$$

ModGCIA is described by the following algorithm, with the powers, m and n, adjusted to optimise the linear correlation coefficient:

$$\text{ModGCIA} = TR^{2.26} * \Sigma\ (DR*FR*WA^{0.34}) \qquad (9)$$

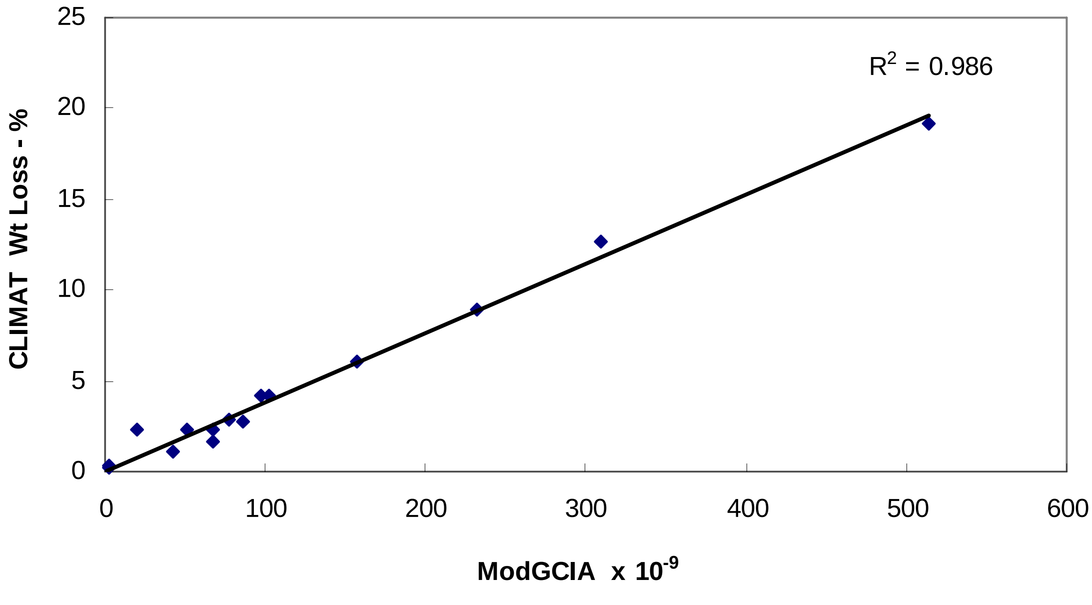

Figure 4. Relationship between ModGCIA and Al/Cu CLIMAT weight loss data for 15 Australian and overseas bases within 200 km of the coast.

3.2 Predicting environmental corrosivity using ModGCIA for sites < 200 km from the coast

Equation (8) in Section 3.1 has been used to predict the environmental corrosivity, as measured by Al/Cu CLIMAT specimens, of several bases and airports of interest to TFSPO in the US and other overseas countries and territories that are < 200 km from the coast. ModGCIA data and ratings, and predicted Al/Cu CLIMAT values, for these sites are given in Appendix F.

The original GCI [1] was used in a similar manner to predict the environmental or atmospheric corrosivity of these overseas sites of interest. This present work with ModGCIA is considered likely to generate more accurate predictions of environmental corrosivity because, compared to the GCI, ModGCIA takes into account a wider range of geographic features and variations in climate in its development.

During the course of this project it became apparent that the earlier predictions [Reference 2 - Appendix F] for the Australian territories, Cocos Island and Christmas Island, were probably in considerable error due to the presence of coral reefs ringing both islands not being taken into account. An annual predicted CLIMAT value for each of these islands has been re-calculated, using ModGCIA, and the relevant data is shown in Appendix F. Comprehensive NOAA wind data was available for Cocos Is. but not for Christmas Is. Annual wind roses at 9.00 am and 3.00 pm were available for both islands [22]. These were all similar in appearance, with the winds being predominantly from the east and south-east, except that the winds on Christmas Is. were significantly weaker than on Cocos Is. The ratio of average wind speed for Christmas Is. and Cocos Is. (0.65) was used to estimate the wind aggregates for Christmas Is., using the Cocos Is. wind aggregates.

3.3 Predicting environmental corrosivity using a simple algorithm for sites > 200 km from the coast

Equation (7) in Section 2.5 has been used to predict the environmental corrosivity, as measured by Al/Cu CLIMAT specimens, of several bases and airports of interest to TFSPO in the US and other overseas countries and territories that are > 200 km from the coast. Relevant data and predicted CLIMAT values for these sites are given in Appendix G.

3.4 Cumulative Corrosion Index

TFSPO indicated [23] that the Al/Cu CLIMAT values predicted from the ModGCIA may be used to calculate the CI for each aircraft:

$$CI = LI*ED/120000 \tag{10}$$

where LI = Location Index based on the CLIMAT value predicted by the ModGCIA.
ED = Exposure Days.

The equation for CI permits the calculation of a cumulative total that estimates the severity of atmospheric corrosivity exposure based on an expected service life for an aircraft of 12000 days (32.9 years). It was agreed with TFSPO that LI would equal the GCIA predicted CLIMAT value when that value was 10 or less, and equal 10 for all GCIA predicted CLIMAT values greater than 10. This means that, for the worst case scenario where an aircraft is always stationed at a location or locations where the LI is 10 or more, the CI would have a value of 1.0 after 32.9 years.

Annual LI values for all overseas bases and airports of interest to TFSPO and considered here are shown in Table 2. The revised LI values for Cocos and Christmas Islands are also shown in the table. These LI values are all based on ModGCIA predictions for locations within 200 km of the coast, and the simple algorithm predictions for locations further inland.

Monthly LI values for Australian bases and airports were given in a previous report [Reference 2 – Table2]. That information is reproduced here in Table 3 (except for Cocos and Christmas Islands), and includes annual LI values to assist with comparisons with overseas bases and airports.

4. Conclusions

After investigating weight loss data at a large number and various types of overseas sites, several improvements have been made to the GCIA that enables the modified index, or ModGCIA, to be used with greater confidence in predicting the environmental corrosivity of sites throughout the world that are within 200 km of the coast. A simple algorithm has been developed to predict the environmental corrosivity of sites more than 200 km from the coast.

The predicted corrosivity for each site can be incorporated into a CI that enables a cumulative or “running” total of atmospheric corrosivity exposure to be created for each aircraft.

5. Acknowledgement

This work was sponsored by TFSPO, RAAF Williamtown.

Table 2. Predicted annual Al/Cu CLIMAT and Location Index for sites of interest

Base or Airport	Predicted CLIMAT value	Location Index
Australia		
Christmas Island	3.54	3.5
Cocos Island	7.87	7.9
US		
Alaska		
Eielson AFB/Fairbanks	0.12	0.12
Elmendorf AFB/Anchorage	0.05	0.05
California		
North Island NAS/San Diego	5.48	5.5
Travis AFB/E of San Francisco	0.41	0.41
Florida		
MacDill AFB/Tampa	2.97	3.0
Hawaii		
Hickam AFB/Honolulu	6.36	6.4
Nevada		
Nellis AFB/Las Vegas	0.05	0.05
Diego Garcia		
Diego Garcia/Indian Ocean	4.31	4.3
Guam		
Andersen AFB/Pacific Ocean	1.91	1.9
Wake		
Wake Airfield/Pacific Ocean	5.01	5.0
Brunei		
Brunei International	10.84	10.8
Canada		
Alberta		
Cold Lake	0.07	0.07
Quebec		
Bagotville	0.11	0.11
Mirabel/Montreal	0.23	0.23
Indonesia		
Denpasar/Bali	9.93	9.9
Jakarta International	4.04	4.0
Malaysia		
Butterworth	4.26	4.3
Kuantan	5.04	5.0
New Zealand		
Ohakea	6.02	6.0
Qatar		
Al Udeid	0.09	0.09
Camp Snoopy/Doha	0.43	0.43
Singapore		
Paya Lebar	6.01	6.0
Thailand		
Khorat	0.48	0.48

Table 3. Monthly and annual Location Index (LI) values for Australian bases and airports.

Base/Airport	Month												Annual
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Alice Springs - NT	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.10
Amberley - Qld	2.1	2.1	2.0	1.8	1.5	1.4	1.2	1.3	1.4	1.7	1.8	2.1	1.8
Canberra – ACT	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.22
Curtin - WA	0.5	0.6	0.4	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.32
Darwin - NT	1.5	1.6	1.4	0.8	0.6	0.5	0.6	0.8	1.0	1.1	1.2	1.4	1.1
East Sale - Vic	3.0	3.4	3.3	2.9	2.5	2.3	2.2	2.3	2.5	2.7	2.8	2.8	2.9
Edinburgh - SA	2.3	2.3	2.6	2.8	3.4	4.0	3.9	4.0	3.7	2.9	2.3	2.5	3.0
Hobart - Tas	1.4	1.4	1.4	1.2	1.1	1.0	1.1	1.1	1.1	1.2	1.3	1.3	1.3
Laverton - Vic	2.1	2.1	2.0	1.8	1.5	1.4	1.2	1.3	1.4	1.7	1.8	2.1	1.7
Learmonth - WA	0.8	1.0	0.9	0.9	1.0	1.2	1.0	0.9	0.7	0.6	0.6	0.6	0.84
Mt. Isa - Qld	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.11
Norfolk Is. - Pacific	9.7	10.0	10.0	9.6	8.5	8.3	7.9	7.8	7.8	8.2	8.5	9.0	8.9
Nowra - NSW	2.9	3.1	2.7	2.3	1.9	1.6	1.5	1.8	1.9	2.2	2.5	2.8	2.3
Pearce - WA	1.9	1.7	1.8	2.2	2.4	3.0	3.1	3.1	3.0	2.5	2.1	2.0	2.6
Richmond - NSW	2.9	3.0	2.9	2.6	2.1	1.6	1.5	1.7	1.9	2.2	2.6	2.4	2.5
Rockhampton - Qld	2.2	2.3	2.2	2.0	1.8	1.6	1.5	1.6	1.6	1.7	1.8	2.0	1.9
Stirling - WA	10.0	9.8	10.0	9.3	8.2	10.0	9.6	10.0	10.0	10.0	10.0	10.0	10.0
Tindal - NT	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.3	0.22
Townsville - Qld	3.7	3.8	3.7	3.5	3.2	2.9	3.0	3.1	3.0	3.1	3.2	3.5	3.3
Weipa - Qld	2.2	2.4	1.9	1.0	0.8	0.7	0.8	1.0	1.0	1.2	1.4	1.8	1.5
Woomera - SA	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.1	0.2	0.21
Williamtown - NSW	4.9	5.3	5.1	4.5	4.0	3.9	3.5	3.6	3.7	3.9	4.2	4.5	4.3

6. References

1. J.C. Bitcon, H. Kades, S.G. Russo and B.R.W. Hinton, DSTO Report DSTO-CR-2005-0188, "Geographic Corrosivity Index – An Empirical Approach to Predicting the Environmental Corrosivity at Airbases", September 2005.
2. J.C. Bitcon & S.G. Russo, DSTO Report DSTO-CR-2006-0222, "Further Development of the Geographic Corrosivity Index to Predict Monthly Variations in Environmental Corrosivity at Airbases", July 2006.
3. ASTM G116 (1993), "Standard Practice for Conducting Wire-on-Bolt Test for Atmospheric Galvanic Corrosion".
4. R.C. Kinzie, "Measuring the rates and impact of corrosion damage", *Aircraft Eng. and Aerospace Tech.,* 2003, **75**, No. 2, 123-129.
5. R.C. Kinzie, "Corrosion Suppression: Managing Internal & External Aging Aircraft Exposure", Proc. of 6th FAA/DoD/NASA Aging Aircraft Conference, San Francisco, CA, September, 2002.
6. R.C. Kinzie, "Anticipating Damage in the Fleet: Development of a Robust Environmental Severity Index", 5th Joint NASA/FAA/DoD Conference on Aging Aircraft, Orlando, FL, September, 2001.
7. "International Station Meteorological Climate Summary" CD, Version 4.0, September 1996, National Climatic Data Center, National Oceanic and Atmospheric Administration, US Department of Commerce.
8. J. Tidblad, A.A. Mikhailov and V. Kucera, "Model for the Prediction of the Time of Wetness from Average Annual data on Relative Air Humidity and Air Temperature", *Protection of Metals,* 2000, **36,** No. 6, 533-540.
9. ISO 9223:1992 Standard, "Corrosion of metals and alloys - Corrosivity of atmospheres - Classification".
10. J.D. Hughes, G.A. King and D.J. O'Brien, "Corrosivity in Antarctica - revelations on the nature of corrosion in the world's coldest, driest, highest and purest continent", Proc. 13th Int. Corrosion Congress, Australia, 25-29 Nov. 1996, **I**, paper 24.
11. I.S. Cole, W.D. Ganther, J.D. Sinclair, D. Lau and D.A. Paterson, "A Study of the Wetting of Metal Surfaces in Order to Understand the Processes Controlling Atmospheric Corrosion", *J. Electrochem. Soc.*, 2004, **151** (12), B627-B635.
12. I.S. Cole and D.A. Paterson, "Mathematical models of dependence of surface temperatures of exposed metal plates on environmental parameters", *Corros. Eng. Sci. Technol.*, 2006, **41**, 67-76.
13. S. Feliu, M. Morcillo and S. Feliu, Jr., "The Prediction of Atmospheric Corrosion from Meteorological and Pollution Parameters - I. Annual Corrosion", *Corros. Sci.*, 1993, **34**, 403-414.
14. S. Feliu, M. Morcillo and S. Feliu, Jr., "The Prediction of Atmospheric Corrosion from Meteorological and Pollution Parameters - II. Long Term Corrosion", *Corros. Sci.*, 1993, **34**, 415-422.
15. S.W. Dean and D.B. Reiser, "Analysis of Long-Term Atmospheric Corrosion Results from ISO CORRAG Program", *Outdoor Atmospheric Corrosion ASTM STP 1421*, H. Townsend, Ed., American Society for Testing and Materials International, West Conshohocken, PA, 2002, pp 3-18.

16. NASA Materials Anaysis Branch Report MTB 099-74, "Relative Corrosivity of Atmospheres At Various Distances From The Coast", January 16, 1980.
17. S. Filiu, M. Morcillo and B. Chico, "Effect of Distance from Sea on Atmospheric Corrosion Rate", *Corrosion,* 1999, **55**, No. 9, 883-891.
18. D. Pieterson, J.P. Holtzhausen and W. L. Vosloo, "An Investigation Into The Methodology To Develop An Insulator Pollution Severity Application Map For South Africa", IEEE AFRICON Conference, Botswana, September 15-17, 2004.
19. I.S. Cole, W.D. Ganther, D.A. Paterson, G.A. King, S.A.Furman and D. Lau, "Holistic model for atmospheric corrosion Part 2 – Experimental measurement of deposition of marine salts in a number of long range studies", *Corros. Eng. Sci. Technol*, 2003, **38**, No. 4, 259-266.
20. R.D. Klassen – The Royal Military College of Canada – unpublished CLIMAT data.
21. DSTO – unpublished CLIMAT data.
22. Australian Bureau of Meteorology: www.bom.gov.au
23. D. Martinek – private communication, March 2006.
24. www.meds-sdmm.dfo-mpo.gc.ca/alphapro/wave/TDCAtlas/TDCImages/ ECMap.gif
25. S & K Technologies Final Technical Report "Project on Global War on Terrorism for Reducing the Impact of Southwest Asia Operations on F-15, C-130, and Other Military Weapon Systems", 8 May, 2006.
26. I.S. Cole, D.A. Paterson, and W.D. Ganther, "Holistic model for atmospheric corrosion Part 1 – Theoretical framework for production, transportation and deposition of marine salts", *Corros. Eng. Sci. Technol.,* 2003, **38**, No. 2, 129-134.
27. www.kwikcast.weatherbase.com

Appendix A: Wind Aggregate

Wind aggregates (WA) for each site were calculated from wind data obtained from the NOAA [7]. Aggregates for each of the four major ordinal wind directions – N, E, S and W – and the four minor ordinal wind directions – NE, SE, SW and NW - were calculated. The NOAA wind data were presented in either of two formats, which are called US or British in this report.

<u>US Format</u>

The wind information for most US and some other sites was given in US format:

The wind data was given for 12 directions specified in degrees: 350° – 010° (N), 020° - 040°, 050° - 070°, 080° - 100° (E), etc. As the directions between the major ordinal directions did not match the minor ordinal directions, the data for these directions was partitioned, as shown below:

Ordinal Direction	US Format Wind Data
N	(350° - 010°) + (020° - 040°)/4 + (320° - 340°)/4
NE	3*(020° - 040°)/4 + 3*(050° - 070°)/4
E	(080° - 100°) + (050° - 070°)/4 + (110° - 130°)/4
SE	3*(110° - 130°)/4 + 3*(140° - 160°)/4
S	(170° - 190°) + (140° - 160°)/4 + (200° - 220°)/4
SW	3*(200° - 220°)/4 + 3*(230° - 250°)/4
W	(260° - 280°) + (230° - 250°)/4 + (290 – 310°)/4
NW	3*(290° - 310°)/4 + 3*(320° - 340°)/4

The percentage of time throughout the year that the wind was blowing from each direction was further broken down into wind speed ranges, which were identified by numbered zones:

Wind Speed Zone	Wind Speed Range – knots
1	5 – 9 (average 7)
2	10 – 14 (average 12)
3	15 – 19 (average 17)
4	20 – 24 (average 22)
5	> 25

Work by Cole *et al.* [26] indicated that the concentration of salt aerosol carried inland by wind increased with wind speed, with the salt concentration in the air increasing in the approximate ratio 1:3:7:13:19 for wind speeds of 7, 12, 17, 22 and 30 knots, respectively. Their work also indicated that the salt aerosol carried inland at wind speeds < 5 knots was negligible. The WA for the US format is as follows:

$$WA = WSZ1 + 3*WSZ2 + 7*WSZ3 + 13*WSZ4 + 19*WSZ5$$

where WSZ1, WSZ2, etc is the percentage of time throughout the year that the wind speed is in the respective wind speed zone 1, 2, etc.

British Format

The wind information for most Australian, Canadian, New Zealand, Asian and some other sites was given in British format:

The wind data was given for 16 directions specified by direction: N, NNE, NE, ENE, E, etc. The data for the 16 wind directions were reduced to the four major and four minor ordinal directions by partioning, as shown below:

Ordinal Direction	British Format Wind Data
N	N + NNW/2 + NNE/2
NE	NE + NNE/2 + ENE/2
E	E + ENE/2 + ESE/2
SE	SE + ESE/2 + SSE/2
S	S + SSE/2 + SSW/2
SW	SW + SSW/2 + WSW/2
W	W + WSW/2 + WNW/2
NW	NW + WNW/2 + NNW/2

The percentage of time throughout the year that the wind was blowing from each direction was further broken down into wind speed ranges, which were identified by numbered zones:

Wind Speed Zone	Wind Speed Range – knots
1	7 – 10 (average 8.5)
2	11 – 16 (average 13.5)
3	17 – 21 (average 19)
4	22 – 27 (average 24.5)
5	> 28

Work by Cole *et al.* [26] indicated that the concentration of salt aerosol carried inland by wind increased with wind speed, with the salt concentration in the air increasing in the approximate ratio 1:3:7:11:17 for wind speeds of 8.5, 13.5, 19, 24.5 and 33 knots, respectively. The wind aggregate (WA) for the British format is as follows:

WA = WSZ1 + 3*WSZ2 + 7*WSZ3 + 11*WSZ4 + 17*WSZ5

where WSZ1, WSZ2, etc is the percentage of time throughout the year that the wind speed is in the respective wind speed zone 1, 2, etc.

Appendix B: GCIA Data for Battelle Sites

(a) Geographic and climate data

Base or Airport	Location	Distance From Coast (km)	Distance Rating (DR)	Coast Description	Geographic Rating (GR)	Average Temp. (°C)	Average Rel. Humidity (%RH)	Calculated TOW (h)
Athens	US - Georgia	308	1	Sea	1	16.6	70.2	3338
Atlantic City	US – New Jersey	16	2	Sea	4	11.9	71.9	3394
Aviano	Nth Italy	52	2	Gulf	3	12.9	71.8	3439
Barksdale	US - Louisiana	303	1	Sea	1	18.6	70.9	3524
Brindisi	Sth Italy	0.8	5	Sea	4	16.7	78.3	4868
Corpus Christi	US - Texas	11	2	Sea	4	23.2	74.8	4364
DAB Airport*	US - Florida	7	3	Sea	4	21.5	76.4	4653
Eareckson	Nth Pacific Is.	0.7	5	Reefs/rocks	2	3.9	80.0	3602
Elmendorf	US - Alaska	4.1	3	Inlet	1	1.9	68.9	1900
Fairchild	US - Washington	498	1	Sea	1	8.6	66.6	2340
Fresno	US - California	181	1	Sea	1	17.4	60.7	1921
Fort Smith	US - Arkansas	620	1	Sea	1	16.1	69.0	3116
Great Falls	US - Montana	980	1	Sea	1	7.3	55.5	1084
Guam	Pacific Is.	1.8	4	Reefs	2	26.2	72.7	3989
Homestead	US - Florida	4.6	3	Reefs	2	24.2	72.9	4006
Hurlburt	US - Florida	3.2	3	Sea	4	19.6	75.2	4364
Kadena	Japan - Okinawa	1.7	4	Reefs	2	22.7	73.4	4081
Kunsan	Sth Korea	0.6	5	Sea	4	13.4	74.3	3913

* Daytona Beach Airport

(a) Geographic and climate data (continued)

Base or Airport	Location	Distance From Coast (km)	Distance Rating (DR)	Coast Description	Geographic Rating (GR)	Average Temp. (°C)	Average Rel. Humidity (%RH)	Calculated TOW (h)
Langley	US - Virginia	0.9	5	Bay	1	15.4	69.7	3209
MacDill	US - Florida	0.9	5	Bay	1	23.0	70.8	3593
McEntire	US - Sth Carolina	152	1	Sea	1	17.4	58.9	1703
Mildenhall	England	80	1	Sea	1	10.3	74.9	3771
Minn. St Paul*	US - Minnesota	1185	1	Sea	1	7.3	68.1	2428
Nellis	US - Nevada	390	1	Sea	1	19.6	30.7	143
Pease	US - New Hamp.	8.7	3	Sea	4	8.9	66.4	2339
Pittsburgh	US - P'sylvania	480	1	Sea	1	10.6	68.0	2678
Shaw	US - Sth Carolina	136	1	Sea	1	17.9	67.5	2920
Sioux City	US - Iowa	1421	1	Sea	1	9.2	69.3	2771
Springfield	US - Illinois	1048	1	Sea	1	11.9	71.0	3239
Taipei	Formosa	18	2	Sea	4	22.8	80.0	5420
Tinker	US - Oklahoma	707	1	Sea	1	15.9	61.7	2019
Toledo	US - Ohio	804	1	Sea	1	9.4	72.6	3302
Tulsa	US - Oklahoma	742	1	Sea	1	15.9	66.2	2657
Warner-Robins	US - Georgia	254	1	Sea	1	18.4	69.8	3324
WPAFB**	US - Ohio	765	1	Sea	1	11.6	71.2	3249

* Minniapolis St. Paul
** Wright-Paterson Air Force Base

(b) Wind, GCIA and weight loss data

Base or Airport	Wind Format	Wind Directions	Wind Data % of time in wind speed zones					Wind Aggr. (WA)	GCIA	Alloy 6061 Wt. Loss (μg/cm²/y)	Alloy 7075 Wt. Loss (μg/cm²/y)
			Wind Speed Zones								
			1	2	3	4	5				
Athens	British	E & SE	6.1	1.6	0.1	0	0	11.3	0.9	200	90
Atlantic City	British	S & E	8.6	6.1	0.9	2.0	0	54.7	19.6	114	
Aviano	US	S & SE	3.2	0.2	0	0	0	3.9	2.8	56	26
Barksdale	US	S & SE	14.1	5.0	0.6	0	0	33.4	1.8	119	90
Brindisi	British	N & NW	10.7	8.4	2.1	0.6	0.3	61.5	49.0	803	1390
Corpus Christi	British	S & SE	15.2	21.2	5.2	1.0	0	125.7	31.4	1030	
DAB Airport	British	E & NE	10.8	8.3	0.8	0	0	41.3	23.1	190	157
Eareckson	US	S & SW	5.0	6.8	5.9	4.4	4.9	212.3	56.8	924	1300
Elmendorf	US	N & NW	11.1	1.9	0.1	0	0	18.0	4.1	159	70
Fairchild	US	W & SW	11.7	6.7	1.8	0.5	0.1	51.9	2.6	136	39
Fresno	British	W & SW	6.5	1.4	0.1	0	0	11.1	1.0	15	
Fort Smith	British	S & SE	5.1	1.8	0.1	0	0	10.9	0.9	11	
Great Falls	British	W & SW	14.1	16.8	8.7	4.8	1.5	201.8	7.0	2	
Guam	British	E & NE	27.9	24.3	1.6	0	0	111.9	29.8	187	740
Homestead	US	E & NE	17.6	6.8	0.7	0	0	42.9	12.2	143	
Hurlburt	US	S & SE	11.9	4.2	0.3	0	0	26.5	17.7	272	736
Kadena	US	W & SW	5.8	4.6	1.1	0.2	0	29.2	12.7	276	336
Kunsan	British	W & NW	8.2	4.2	1.2	0.4	0	33.1	34.7	603	1217

(b) Wind, GCIA and weight loss data (continued)

Base or Airport	Wind Format	Wind Directions	Wind Data % of time in wind speed zones					Wind Aggr. (WA)	GCIA	Alloy 6061 Wt. Loss (μg/cm²/y)	Alloy 7075 Wt. Loss (μg/cm²/y)
			Wind Speed Zones								
			1	**2**	**3**	**4**	**5**				
Langley	US	E & NE	10.2	4.7	0.9	0.2	0	33.1	9.0	494	484
MacDill	US	E & NE	16.8	4.9	0.5	0	0	35.0	9.1	564	464
McEntire	US	S & SE	6.3	1.5	0	0	0	10.8	1.0	54	
Mildenhall	British	N & SE	5.8	3.0	0.3	0	0	16.7	1.1	211	736
Minn. St Paul	British	N & SE	10.0	7.6	1.4	0.2	0	44.5	2.3	64	90
Nellis	US	W & SW	3.0	2.3	1.3	0.6	0.1	26.2	2.9	15	
Pease	US	E & SE	6.3	1.6	0.2	0	0	12.5	12.5	126	150
Pittsburgh	British	E & SE	5.8	2.0	0	0	0	11.8	1.0	143	87
Shaw	US	S & SE	5.7	1.5	0.2	0	0	11.3	0.9	75	
Sioux City	British	S & SE	13.3	10.4	2.6	0.4	0	66.6	2.9	38	
Springfield	British	S & SE	10.2	9.7	2.7	0.5	0	62.8	2.7	106	64
Taipei	British	E & NE	20.3	16.1	1.2	0.1	0	78.1	22.3	146	
Tinker	US	S & SE	17.6	12.2	3.4	0.7	0	87.0	3.6	58	
Toledo	British	E & SE	6.2	2.7	0.2	0	0	15.3	1.1	178	130
Tulsa	British	S & SE	17.2	13.1	3.0	0.6	0	84.0	3.4	32	
Warner-Robins	US	E & SE	7.3	1.3	0	0	0	11.1	0.9	66	
WPAFB	US	E & SE	5.6	1.5	0.1	0	0	10.8	0.9	234	

Appendix C: ModGCIA Data for Battelle Sites < 200km from Coast

(a) Calculation of Geographic Ranking

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones Wind Speed Zones 1	2	3	4	5	Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
Atlantic City	NE	59	2	124	16	2.2	1.7	0.3	0.1	0	9.5	2.5	80.4
	E	22	2	> 1000	32	2.9	1.9	0.3	0.1	0	10.7	2.6	169.1
	SE	16	2	> 1000	32	2.7	1.2	0.1	0	0	6.9	2.2	140.9
	S	20	2	125	16	5.8	4.2	0.6	0.2	0	24.2	3.7	118.2
	SW	43	2	44	14	5.3	2.9	0.5	0.1	0	18.1	3.3	91.8
												Geographic Rating:	**600.4**
Aviano	N	918	0.1	72	14	4.3	0.4	0.03	0	0	5.5	2.0	2.8
	SE	56	2	47	14	1.1	0.1	0	0	0	1.4	1.1	31.9
	S	61	1	156	16	2.1	0.2	0	0	0	2.5	1.5	23.3
	SW	305	0.1	658	26	1.9	0.2	0	0	0	2.1	1.3	3.5
	NW	929	0.1	132	16	0.3	0	0	0	0	0.3	0.6	0.9
												Geographic Rating:	**62.4**
Brindisi	N	1.5	6	222	16	4.7	3.3	0.9	0.3	0.2	27.6	3.9	373.9
	NE	1.2	7	182	16	2.0	1.2	0.4	0.2	0.1	10.7	2.6	296.0
	E	4	4	110	16	2.0	0.6	0.2	0	0	5.2	2.0	125.3
	SE	11	3	303	18	2.2	1.3	0.4	0.2	0	11.1	2.7	144.6
	S	54	2	> 1000	32	4.2	3.0	0.9	0.4	0	23.0	3.6	231.3
	SW	55	2	105	16	1.7	1.0	0.2	0.1	0	6.5	2.2	68.9
	W	263	0.3	39	12	2.8	2.1	0.5	0.2	0	13.9	2.9	10.6
	NW	3.9	4	647	26	6.1	5.1	1.2	0.3	0.1	33.9	4.2	441.0
												Geographic Rating:	**1691.6**

(a) Calculation of Geographic Ranking (continued)

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones – Wind Speed Zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						1	2	3	4	5			
Corpus Christi	N	1.1	7	19	12	3.7	4.3	1.5	0.5	0.1	34.3	4.3	357.9
	NE	1.3	6	18	12	3.9	3.4	0.7	0.2	0	21.1	3.5	251.1
	E	12.8	3	> 1000	32	5.4	4.3	0.6	0.1	0	22.5	3.6	344.1
	SE	11.7	3	> 1000	32	9.4	13.8	3.3	0.6	0	79.9	6.0	578.5
	S	26.3	2	93	14	5.9	7.4	1.9	0.4	0	45.8	4.8	134.3
	NW	2.0	5	13	12	1.0	1.2	0.4	0.2	0	9.5	2.5	150.7
												Geographic Rating:	**1816.6**
DAB Airport	N	19	2	265	16	3.3	3.3	0.5	0	0	16.6	3.2	101.1
	NE	7.6	4	> 1000	32	4.4	3.6	0.4	0	0	18.0	3.3	418.7
	E	7.8	4	> 1000	32	6.4	4.7	0.4	0	0	23.3	3.6	465.0
	SE	24	2	368	18	3.7	2.1	0.2	0	0	11.4	2.7	97.6
	S	449	0.1	217	16	3.2	1.3	0.2	0	0	8.3	2.4	3.8
	SW	232	0.3	> 1000	32	3.5	1.7	0.3	0	0	10.7	2.6	25.3
	W	173	0.5	> 1000	32	3.4	2.1	0.4	0.1	0	13.1	2.9	45.9
												Geographic Rating:	**1157.4**
Eareckson	N	1.8	6	Rocks	5	3.0	4.3	3.5	2.4	1.7	101.0	6.6	199.0
	NE	2.1	5	Rocks	5	2.1	3.1	2.4	2.0	1.6	81.6	6.1	151.9
	E	2.5	5	Rocks	5	1.6	2.1	1.5	1.1	0.9	48.7	4.9	123.0
	SE	1.1	7	Rocks	5	1.8	2.3	1.8	1.2	1.3	60.1	5.4	187.7
	S	0.7	8	Rocks	5	2.1	2.9	2.4	1.7	2.1	88.4	6.3	251.3
	SW	0.8	7	33	12	2.9	3.9	3.5	2.7	2.9	125.8	7.3	609.8
	W	1.9	5	Rocks	5	2.8	3.2	2.2	1.3	0.9	61.1	5.4	134.9
	NW	3.2	4	880	26	2.9	3.9	2.8	1.6	1.1	73.0	5.8	603.9
												Geographic Rating:	**2261.5**

(a) Calculation of Geographic Ranking (continued)

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones — Wind Speed Zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						1	**2**	**3**	**4**	**5**			
Elmendorf	SE	188	0.5	> 1000	32	0.4	0.2	0	0	0	0.8	0.9	14.8
	S	180	0.5	> 1000	32	2.0	0.8	0.2	0	0	5.5	2.0	32.2
	SW	113	1	227	16	2.7	0.8	0.2	0	0	6.2	2.1	33.9
	W	800	0.1	> 1000	32	4.5	0.4	0	0	0	5.7	2.0	6.5
	NW	966	0.1	> 1000	32	2.3	0.4	0	0	0	3.5	1.7	5.3
												Geographic Rating:	**92.7**
Fresno	S	262	0.3	39	12	1.3	0.2	0	0	0	1.9	1.3	4.7
	SW	180	0.5	> 1000	32	0.8	0	0	0	0	0.8	0.9	14.2
	W	185	0.5	> 1000	32	5.8	1.4	0.1	0	0	10.3	2.6	41.6
	NW	577	0.1	> 1000	32	11.5	4.4	0.3	0	0	26.3	3.8	12.2
												Geographic Rating:	**72.7**
Guam	N	1.9	5	Reefs	5	0.8	0.3	0	0	0	1.6	1.2	29.9
	NE	2.6	5	Reefs	5	7.6	7.2	0.4	0	0	31.5	4.1	102.9
	E	2.3	5	Reefs	5	20.3	17.1	1.3	0	0	80.4	6.0	151.0
	SE	2.2	5	Reefs	5	5.3	3.0	0.2	0	0	15.6	3.1	77.0
	S	5.9	4	Reefs	5	1.6	0.5	0	0	0	3.1	1.6	31.6
	SW	42.3	2	Reefs	5	1.0	0.4	0	0	0	2.2	1.4	13.7
	W	10.6	3	Reefs	5	1.3	0.6	0	0	0	3.1	1.6	23.9
	NW	11.0	3	Reefs	5	0.6	0.2	0	0	0	1.1	1.0	15.3
												Geographic Rating:	**445.3**

(a) Calculation of Geographic Ranking (continued)

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						Wind Speed Zones							
						1	2	3	4	5			
Homestead	N	247	0.3	503	18	4.3	1.3	0.2	0	0	9.2	2.5	13.4
	NE	32	2	Reefs	5	5.8	2.9	0.4	0	0	17.2	3.2	32.1
	E	21	2	Reefs	5	11.8	3.9	0.3	0	0	25.7	3.8	37.8
	SE	21	2	Reefs	5	6.1	1.7	0.2	0	0	12.1	2.8	27.8
	S	41	2	Reefs	5	2.5	0.8	0.1	0	0	5.2	2.0	19.7
	SW	53	2	80	14	1.3	0.7	0.2	0	0	4.4	1.8	51.3
	W	82	1	> 1000	32	1.3	0.5	0.2	0	0	3.8	1.7	55.4
	NW	334	0.1	302	18	2.7	0.8	0.2	0	0	6.2	2.1	3.8
												Geographic Rating:	**241.3**
Hurlburt	E	10	3	42	14	4.7	1.5	0	0	0	9.4	2.5	105.2
	SE	4.4	4	618	26	5.9	2.4	0.2	0	0	14.2	3.0	308.5
	S	3.2	4	> 1000	32	6.0	1.8	0.1	0	0	12.3	2.8	358.3
	SW	4.7	4	> 1000	32	6.4	2.0	0.1	0	0	13.0	2.9	366.7
												Geographic Rating:	**1138.7**
Kadena	N	8.7	3	Reefs	5	5.9	6.5	2.4	0.4	0	46.6	4.8	72.5
	NE	9.9	3	Reefs	5	9.6	5.1	1.2	0.2	0	35.1	4.3	64.5
	E	11.5	3	Reefs	5	6.5	3.7	1.0	0.3	0	27.4	3.9	58.3
	SE	8.1	3	Reefs	5	4.2	2.1	0.5	0.1	0	14.6	3.0	45.0
	S	25.3	2	Reefs	5	2.8	1.3	0.3	0	0	9.4	2.5	25.0
	SW	2.1	5	Reefs	5	3.5	2.9	0.8	0.2	0	19.4	3.4	84.3
	W	2.1	5	Reefs	5	2.3	1.7	0.3	0	0	9.8	2.6	63.7
	NW	5.4	4	Reefs	5	1.6	1.1	0.4	0.1	0	8.4	2.4	47.7
												Geographic Rating:	**461.0**

(a) Calculation of Geographic Ranking (continued)

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
Kunsan	N	8.3	3	14	12	4.3	3.0	0.6	0.1	0	18.1	3.3	117.9
	NE	292	0.3	> 1000	32	2.1	0.6	0	0	0	3.7	1.7	16.4
	E	263	0.3	471	18	2.0	0.3	0	0	0	2.7	1.5	8.1
	SE	190	0.5	203	16	1.4	0.3	0	0	0	2.1	1.4	10.8
	S	1.6	6	2.7	5	1.5	1.0	0.2	0	0	5.8	2.1	61.5
	SW	0.7	8	13	12	2.1	1.3	0.2	0	0	7.4	2.3	218.1
	W	0.6	8	590	18	3.0	0.9	0.2	0.1	0	7.5	2.3	328.1
	NW	0.9	7	5.9	10	5.3	3.3	1.0	0.4	0	25.7	3.8	264.7
												Geographic Rating:	**1025.6**
Langley	N	122	0.5	53	14	5.5	4.4	1.1	0.3	0	29.4	4.0	28.0
	NE	7.0	4	40	12	5.7	3.4	0.8	0.2	0	22.9	3.6	173.3
	E	6.9	4	> 1000	32	4.5	1.4	0.2	0	0	10.2	2.6	331.7
	SE	51	2	> 1000	32	3.0	0.8	0	0	0	5.3	2.0	126.3
	S	249	0.3	> 1000	32	5.0	2.9	0.5	0	0	17.5	3.2	31.1
												Geographic Rating:	**690.4**
MacDill	NE	1.3	6	6.8	10	8.6	2.9	0.3	0	0	19.3	3.4	201.9
	E	1.6	6	7.7	10	8.2	2.1	0.2	0	0	15.7	3.1	185.5
	SE	330	0.1	320	18	5.3	1.2	0.1	0	0	9.5	2.5	4.5
	S	75	1	450	18	3.7	1.1	0.2	0	0	8.3	2.4	42.9
	SW	23	2	> 1000	32	4.0	1.4	0.2	0	0	9.9	2.6	163.7
	W	34	2	> 1000	32	3.5	0.7	0.2	0	0	6.8	2.2	140.3
	NW	39	2	260	16	5.5	1.6	0.2	0	0	11.8	2.8	88.1
												Geographic Rating:	**826.9**

(a) Calculation of Geographic Ranking (continued)

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
McEntire	NE	738	0.1	401	18	6.7	1.7	0	0	0	11.9	2.8	5.0
	E	263	0.3	> 1000	32	3.9	0.8	0	0	0	6.2	2.1	20.3
	SE	160	0.5	> 1000	32	2.9	0.6	0	0	0	4.7	1.9	30.3
	S	200	0.5	356	18	3.4	0.9	0	0	0	6.0	2.1	18.8
	SW	616	0.1	> 1000	32	5.0	1.7	0	0	0	10.0	2.6	8.2
												Geographic Rating:	**82.6**
Mildenhall	N	65	1	> 1000	32	3.4	1.7	0.2	0	0	9.4	2.5	80.0
	NE	86	1	866	26	2.2	1.1	0.2	0	0	6.4	2.1	55.5
	E	83	1	192	16	2.4	1.2	0.2	0	0	7.1	2.2	35.6
	SE	78	1	124	16	2.4	1.3	0.2	0	0	7.4	2.3	36.3
	S	169	0.3	114	16	4.2	3.1	0.6	0.2	0	19.2	3.4	26.8
	SW	273	0.5	> 1000	32	6.1	5.7	1.4	0.5	0	37.6	4.4	42.5
	W	315	0.1	224	16	5.1	3.3	1.2	0.4	0	26.8	3.9	6.2
	NW	728	0.1	> 1000	32	2.5	1.6	0.3	0.1	0	9.8	2.6	8.2
												Geographic Rating:	**291.1**
Pease	NE	26	2	83	14	3.0	1.2	0.2	0	0	8.2	2.4	66.4
	E	13	3	> 1000	32	2.4	0.7	0.1	0	0	4.9	1.9	183.6
	SE	9.8	3	> 1000	32	3.9	0.9	0.2	0	0	7.7	2.3	221.1
	S	58	2	32	12	2.9	0.6	0	0	0	5.0	1.9	46.4
												Geographic Rating:	**517.5**

(a) Calculation of Geographic Ranking (continued)

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones — Wind Speed Zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						1	**2**	**3**	**4**	**5**			
Shaw	NE	674	0.1	512	18	7.0	2.8	0.3	0	0	17.4	3.2	3.2
	E	235	0.3	> 1000	32	2.5	0.6	0	0	0	4.4	1.8	17.6
	SE	147	0.5	> 1000	32	1.8	0.3	0	0	0	2.7	1.5	24.0
	S	181	0.5	488	18	3.9	1.2	0.2	0	0	8.6	2.4	21.8
	SW	661	0.1	> 1000	32	6.2	2.3	0.4	0.1	0	16.8	3.2	3.8
												Geographic Rating:	**70.4**
Taipei	N	25	2	332	18	0.4	0.1	0	0	0	0.6	0.8	28.2
	NE	19	2	> 1000	32	2.0	1.8	0.2	0	0	8.7	2.4	155.0
	E	38	2	> 1000	32	18.3	14.4	1.0	0.1	0	69.4	5.7	364.0
	SE	38	2	> 1000	32	3.0	1.4	0.1	0	0	7.8	2.3	148.2
	S	146	0.5	576	18	0.2	0	0	0	0	0.2	0.5	4.1
	SW	184	0.5	> 1000	32	0.3	0.1	0	0	0	0.4	0.7	11.0
	W	45	2	198	16	2.3	0.9	0.1	0	0	5.7	2.0	65.1
	NW	20	2	212	16	2.2	0.5	0	0	0	3.6	1.7	53.8
												Geographic Rating:	**829.4**

(b) Calculation of ModGCIA

Base or Airport	Calculated TOW (h)	Power TOW	Geographic Rating (GR)	ModGCIA
Atlantic City	3394	0.0494	600.3	29.7
Aviano	3439	0.0491	62.4	3.1
Brindisi	4868	0.0432	1691.6	73.1
Corpus Christi	4364	0.0450	1816.6	81.7
DAB Airport	4653	0.0439	1157.4	50.9
Eareckson	3602	0.0483	2261.5	109.3
Elmendorf	1900	0.0612	92.7	5.7
Fresno	1921	0.0610	72.7	4.4
Guam	3989	0.0465	445.3	20.7
Homestead	3948	0.0467	241.3	11.3
Hurlburt	4364	0.0450	1138.7	51.2
Kadena	4081	0.0461	461.0	21.3
Kunsan	3913	0.0469	1025.6	48.1
Langley	3209	0.0504	690.4	34.8
MacDill	3593	0.0484	826.9	40.0
McEntire	1703	0.0637	82.6	5.3
Mildenhall	3771	0.0475	365.6	17.4
Pease	2339	0.0567	517.5	29.3
Shaw	2920	0.0522	70.4	3.7
Taipei	5420	0.0415	829.4	34.4

Appendix D: Simple Algorithm Data for Sites > 200km from Coast

Base or Airport	Distance from Coast (km)	Average Temperature (°C)	Average Relative Humidity (%)	Calculated Average TOW (h)	Average TOW $^{0.49}$/ Dist. from Coast (h $^{0.49}$/km)	Individual Al/Cu CLIMAT Wt. Loss Results (%)	Average Al/Cu CLIMAT Wt. Loss (%)
Tindal	250	27.0	58.3	1711	0.15	0.27, 0.10, 0.81, 0.13, 0.10, 0.35, 0.11, 0.25, 0.32	0.27
Trenton	485	7.1	75.0	3405	0.11	0.15, 0.06, 0.16, 0.79, 0.07, 0.03, 0.13	0.20
Winnipeg	900	2.9	71.9	2374	0.05	0.14, 0.05, 0.11, 0.15, 0.06, 0.03, 0.13	0.10

Appendix E: ModGCIA & CLIMAT Data for Selected Sites

(a) Calculation of Geographic Ranking – Australian sites

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones — Wind Speed Zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						1	2	3	4	5			
Darwin (B)*	N	7.1	4	54	14	3.4	1.4	0	0	0	7.5	2.0	110.9
	NE	37	2	124	16	2.4	1.2	0	0	0	5.9	1.8	58.3
	E	646	0.1	520	18	4.0	2.8	0.3	0	0	14.0	2.5	4.4
	SW	122	0.5	290	16	0.8	0.3	0	0	0	1.7	1.2	9.6
	W	32	2	> 1000	32	5.0	3.0	0.3	0	0	16.1	2.6	164.5
	NW	5.5	4	92	14	6.1	3.1	0.2	0	0	16.8	2.6	146.0
												Geographic Rating:	**493.6**
East Sale (B)	NE	404	0.1	> 1000	32	2.0	1.7	1.0	0.5	0.2	21.2	2.8	9.0
	E	37	2	> 1000	32	3.1	2.3	0.7	0.3	0.1	18.9	2.7	173.7
	SE	25	2	> 1000	32	2.1	1.2	0.2	0.1	0	7.5	2.0	126.7
	S	36	2	285	16	0.8	0.4	0.1	0	0	2.7	1.4	44.9
	SW	118	1	> 1000	32	2.0	2.1	0.8	0.4	0.1	18.3	2.7	85.9
	W	176	0.5	53	14	6.3	6.5	3.0	1.5	0.5	71.4	4.3	29.9
												Geographic Rating:	**470.1**
Nowra (B)	NE	41	2	> 1000	32	1.8	0.8	0.1	0	0	4.5	1.7	106.7
	E	21	2	> 1000	32	1.9	0.8	0.1	0	0	4.5	1.7	106.7
	SE	29	2	> 1000	32	2.2	1.1	0.2	0	0	6.7	1.9	122.2
	S	30	2	> 1000	32	3.7	2.7	0.6	0.2	0	17.6	2.7	169.7
	SW	594	0.1	> 1000	32	1.6	1.1	0.3	0.2	0	9.2	2.1	6.8
												Geographic Rating:	**512.1**

* British format wind data.

(a) Calculation of Geographic Ranking – Australian sites (continued)

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones Wind Speed Zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						1	2	3	4	5			
Richmond (B)	NE	227	0.3	> 1000	32	1.8	0.6	0	0	0	3.6	1.6	14.8
	E	52	2	> 1000	32	1.9	0.7	0	0	0	4.0	1.6	102.1
	SE	62	2	> 1000	32	2.2	1.5	0.2	0	0	7.7	2.0	128.1
	S	173	0.5	> 1000	32	2.5	1.8	0.4	0.1	0	11.5	2.3	36.7
	SW	752	0.1	> 1000	32	1.9	1.6	0.5	0.2	0	11.9	2.3	7.4
												Geographic Rating:	**289.1**
Townsville (B)	N	8.0	4	> 1000	32	3.1	1.1	0	0	0	6.2	1.9	238.0
	NE	3.1	4	> 1000	32	8.3	6.2	0.7	0	0	31.5	3.2	413.4
	E	31	4	> 1000	32	6.4	6.2	1.1	0.1	0	33.3	3.3	210.8
	SE	407	0.1	63	14	3.3	1.7	0.2	0	0	9.8	2.2	3.0
	NW	10	3	62	14	0.9	0.2	0	0	0	1.5	1.1	47.7
												Geographic Rating:	**912.9**
Williamtown (B)	N	962	0.1	> 1000	32	0.5	0.1	0	0	0	0.8	0.9	2.9
	NE	93	1	> 1000	32	2.2	1.0	0.2	0	0	6.2	1.9	59.5
	E	16	2	> 1000	32	2.6	1.5	0.2	0	0	8.3	2.1	131.4
	SE	6.4	4	> 1000	32	3.4	2.1	0.4	0.2	0	14.1	2.5	314.7
	S	7.1	4	> 1000	32	2.9	3.1	0.9	0.4	0.1	24.4	3.0	379.3
	SW	864	0.1	> 1000	32	1.7	1.2	0.4	0.2	0	9.7	2.2	6.9
												Geographic Rating:	**894.7**

(a) Calculation of Geographic Ranking – Canadian sites

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						Wind Speed Zones							
						1	2	3	4	5			
Bagotville (B)	E	117	1	40	12	7.1	6.3	1.5	0.2	0	38.3	3.5	41.4
	SE	511	0.1	60	14	1.0	0.6	0.1	0	0	3.3	1.5	2.1
	S	755	0.1	> 1000	32	0.5	0.2	0	0	0	1.1	1.0	3.3
	NW	922	0.1	> 1000	32	2.6	2.7	0.9	0.3	0.1	20.1	2.8	8.9
												Geographic Rating:	**55.7**
Comox (B)	N	2.1	5	26	12	4.1	1.7	0.2	0	0	10.6	2.2	133.7
	E	1.4	6	19	12	1.1	0.6	0.3	0.3	0	7.6	2.0	143.2
	S	113	1	> 1000	32	2.3	2.0	0.4	0.2	0	12.8	2.4	76.0
	SW	98	1	> 1000	32	0.4	0.2	0	0	0	0.9	1.0	30.3
	W	145	0.5	> 1000	32	1.2	0.1	0	0	0	1.5	1.1	18.2
	NW	354	0.1	325	18	4.6	2.3	0.2	0	0	12.9	2.4	4.3
												Geographic Rating:	**405.6**
Esquimalt* (B)	N	57	2	44	14	0.6	0.1	0	0	0	0.7	0.9	24.8
	E	9.6	3	48	14	1.9	0.5	0.1	0	0	3.6	1.5	64.6
	SE	0.01	9	52	14	4.9	1.9	0.2	0	0	11.5	2.3	289.1
	S	0.01	9	32	12	2.0	0.8	0.1	0	0	4.7	1.7	182.8
	SW	17	2	26	12	1.7	1.0	0.2	0	0	5.6	1.8	43.1
	W	48	2	> 1000	32	3.5	1.2	0.2	0	0	8.1	2.0	130.3
	NW	432	0.1	377	18	1.2	0.2	0	0	0	1.8	1.2	2.2
												Geographic Rating:	**736.9**

* Victoria International Airport wind data [7] (15 km from Esquimalt).

(a) Calculation of Geographic Ranking – Canadian sites (continued)

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
Goose Bay (B)	N	277	0.3	> 1000	32	3.0	2.3	0.3	0.1	0	12.5	2.4	22.7
	NE	31	2	49	14	4.5	3.1	0.7	0.2	0	20.4	2.8	78.0
	E	313	0.1	> 1000	32	1.7	0.7	0.1	0	0	4.2	1.6	5.2
	SE	288	0.3	58	14	0.6	0.3	0	0	0	1.5	1.2	4.8
	S	342	0.1	353	18	3.6	1.9	0.2	0	0	10.2	2.2	4.0
	SW	486	0.1	241	16	4.5	4.5	1.0	0.3	0	27.6	3.1	4.9
												Geographic Rating:	**119.6**
Greenwood* (B)	N	234	0.3	41	14	2.2	2.3	2.9	1.9	3.4	108.1	4.9	20.6
	NE	141	0.5	42	14	1.4	1.2	1.4	1.1	1.7	55.9	3.9	27.5
	E	226	0.3	> 1000	32	1.5	1.1	1.2	0.9	1.4	46.8	3.7	35.5
	SE	84	1	> 1000	32	1.5	1.3	1.0	0.9	1.1	40.4	3.5	112.5
	S	131	0.5	> 1000	32	2.8	3.1	3.6	2.4	2.3	101.7	4.8	77.0
	SW	142	0.5	> 1000	32	2.9	3.8	5.1	3.2	3.2	139.4	5.4	85.7
	W	21	2	138	16	2.9	3.2	3.6	2.6	4.2	137.8	5.3	170.8
	NW	13	3	49	14	2.1	2.2	2.7	2.2	4.3	124.0	5.2	216.3
												Geographic Rating:	**746.0**

* Bay of Fundy wind data [24] (15 km from Greenwood).

(a) Calculation of Geographic Ranking – New Zealand sites

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
Invercargill (B)	N	263	0.3	> 1000	32	4.8	2.7	0.8	0.3	0	21.7	2.8	27.3
	NE	290	0.3	147	16	2.2	0.7	0.1	0	0	4.6	1.7	8.1
	E	113	1	> 1000	32	2.1	1.5	0.4	0.1	0	10.3	2.2	70.7
	SE	27	2	> 1000	32	1.9	1.9	0.4	0.1	0	10.4	2.2	141.9
	S	23	2	> 1000	32	1.9	1.7	0.4	0.2	0	11.8	2.3	148.1
	SW	65	2	> 1000	32	2.1	2.9	1.7	0.9	0.2	35.5	3.4	215.4
	W	8.7	3	> 1000	32	3.0	6.0	4.4	3.7	1.8	121.9	5.1	491.4
	NW	170	0.5	> 1000	32	3.1	3.1	1.1	0.5	0.1	25.7	3.0	48.3
												Geographic Rating:	**1151.2**
Ohakea (B)	N	457	0.1	> 1000	32	5.7	1.7	0.2	0.1	0	12.6	2.4	7.6
	NE	363	0.1	> 1000	32	3.3	0.4	0	0	0	4.3	1.6	5.3
	E	121	0.5	> 1000	32	3.6	3.2	1.2	0.4	0.1	26.1	3.0	48.5
	SE	104	1	> 1000	32	2.0	3.3	1.8	0.8	0.2	35.5	3.4	107.7
	S	153	0.5	> 1000	32	0.8	0.6	0.2	0.1	0	4.7	1.7	27.1
	SW	19	2	111	16	1.6	1.1	0.4	0.2	0	9.0	2.1	67.4
	W	15	3	> 1000	32	3.3	5.2	2.9	1.9	0.4	66.6	4.2	400.1
	NW	173	0.5	> 1000	32	4.8	6.2	2.8	1.8	0.4	68.9	4.2	67.5
												Geographic Rating:	**731.1**

(a) Calculation of Geographic Ranking – New Zealand sites (continued)

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
Tiwai Pt.* (B)	N	287	0.3	> 1000	32	4.8	2.7	0.8	0.3	0	21.7	2.8	27.3
	NE	247	0.3	147	16	2.2	0.7	0.1	0	0	4.6	1.7	8.1
	E	92	1	> 1000	32	2.1	1.5	0.4	0.1	0	10.3	2.2	70.7
	SE	3.6	4	> 1000	32	1.9	1.9	0.4	0.1	0	10.4	2.2	283.8
	S	1.5	6	> 1000	32	1.9	1.7	0.4	0.2	0	11.8	2.3	444.4
	SW	7.1	4	30	12	2.1	2.9	1.7	0.9	0.2	35.5	3.4	161.6
	W	9.7	3	> 1000	32	3.0	6.0	4.4	3.7	1.8	121.9	5.1	491.4
	NW	184	0.5	> 1000	32	3.1	3.1	1.1	0.5	0.1	25.7	3.0	48.3
												Geographic Rating:	**1535.5**

* Invercargill wind data [7] (15 km from Tiwai Pt.).

(a) Calculation of Geographic Factor – US site

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones — Wind Speed Zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						1	**2**	**3**	**4**	**5**			
KSC* (US)**	N	0.1	9	400	18	5.5	2.7	0.4	0	0	16.5	2.6	419.9
	NE	0.1	9	> 1000	32	5.8	2.1	0.2	0	0	13.1	2.4	691.2
	E	0.1	9	> 1000	32	7.3	1.9	0	0.1	0	13.0	2.4	689.6
	SE	0.4	8	262	16	6.5	1.9	0.2	0	0	13.2	2.4	307.9
	S	20	2	32	12	5.3	1.8	0.3	0	0	12.5	2.4	56.7
	SW	255	0.3	848	26	5.0	1.1	0.2	0	0	9.4	2.1	16.7
	W	203	0.3	> 1000	32	3.7	1.2	0.3	0	0	9.1	2.1	20.3
												Geographic Rating:	**2202.3**

* KSC airport wind data [7] (4 km from CLIMAT exposure site).
** US format wind data.

(b) ModGCIA and CLIMAT data

Base or Airport	Location	Ave. Temp. (°C)	Ave. Rel. Humidity (%RH)	Calculated TOW (h)	Power TOW x 10^{-6}	Geographic Rating (GR)	ModGCIA x 10^{-9}	Average CLIMAT (%)
Darwin	Australia - NT	27.7	68.6	3239	85.8	493.6	42.4	1.08
East Sale	Australia – Vic	13.9	76.3	4319	164.5	470.1	77.3	2.84
Nowra	Australia – NSW	16.4	71.0	3473	100.5	512.1	51.4	2.27
Richmond	Australia – NSW	17.6	67.9	2977	70.9	289.1	20.5	2.35
Townsville	Australia – Qld	24.3	69.5	3372	94.0	912.9	85.8	2.72
Williamtown	Australia - NSW	17.7	71.9	3680	114.5	894.7	102.4	4.14
Bagotville	Canada - Quebec	2.5	74.3	2598	52.1	55.7	2.9	0.32
Comox	Canada - Br. Columbia	9.7	78.5	4329	165.3	405.6	67.0	2.31
Esquimalt	Canada - Br. Columbia	9.7	76.1	3914	131.6	736.9	97.0	4.21
Goose Bay	Canada - Labrador	-0.3	70.1	1704	20.1	119.6	2.4	0.17
Greenwood	Canada - New B'wick	6.8	74.6	3309	90.1	746.0	67.2	1.62
Invercargill	New Zealand – Sth. Is.	10.2	80.4	4726	201.5	1151.2	232.0	8.89
Ohakea	New Zealand – Nth. Is.	13.4	79.4	4870	215.7	731.1	157.7	6.08
Tiwai Pt.	New Zealand – Sth. Is.	10.2	80.4	4726	201.5	1535.5	309.4	12.64
KSC*	US – Florida	22.4	78.2	5040	233.1	2202.3	513.4	19.17

* Kennedy Space Centre

Appendix F: ModGCIA Data for Predicted Sites < 200 km from Coast

(a) Calculation of Geographic Factor – US bases

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones — Wind Speed Zones 1	2	3	4	5	Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
Diego Garcia (B)*	N	9.7	3	Reefs	5	1.2	0.6	0	0	0	3.0	1.5	21.8
	NE	7.0	4	Reefs	5	0.6	0.2	0	0	0	1.2	1.1	21.0
	E	8.1	3	Reefs	5	6.7	3.6	0.3	0	0	19.1	2.7	40.9
	SE	11.4	3	Reefs	5	13.2	9.7	0.5	0	0	45.8	3.7	55.0
	S	0.7	8	Reefs	5	5.2	2.7	0.1	0	0	13.7	2.4	97.3
	SW	0.7	8	Reefs	5	1.4	0.5	0	0	0	2.8	1.4	56.4
	W	1.4	6	Reefs	5	3.9	2.3	0.3	0.1	0	13.8	2.4	73.2
	NW	8.1	3	Reefs	5	3.1	2.0	0.2	0	0	10.4	2.2	33.2
												Geographic Rating:	**398.8**
Elmendorf (US)*	SE	188	0.3	> 1000	32	0.3	0.1	0	0	0	0.8	0.9	9.0
	S	180	0.3	> 1000	32	2.1	0.9	0.2	0	0	5.5	1.8	17.1
	SW	113	0.5	227	16	2.4	0.7	0.1	0	0	6.2	1.9	14.9
	W	841	0.1	> 1000	32	4.7	0.4	0	0	0	5.7	1.8	5.8
	NW	966	0.1	> 1000	32	2.1	0.3	0	0	0	3.5	1.5	4.9
												Geographic Rating:	**51.7**

* B = British format wind data, US = US format wind data.

(a) Calculation of Geographic Factor – US bases (continued)

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones — Wind Speed Zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						1	**2**	**3**	**4**	**5**			
Guam (B)	N	1.9	5	Reefs	5	0.8	0.3	0	0	0	1.6	1.2	29.0
	NE	2.6	5	Reefs	5	7.6	7.2	0.4	0	0	31.5	3.2	80.8
	E	2.3	5	Reefs	5	20.3	17.1	1.3	0	0	80.4	4.4	111.1
	SE	2.2	5	Reefs	5	5.3	3.0	0.2	0	0	15.6	2.5	63.6
	S	5.9	4	Reefs	5	1.6	0.5	0	0	0	3.1	1.5	29.2
	SW	42	2	Reefs	5	1.0	0.4	0	0	0	2.2	1.3	13.0
	W	11	3	Reefs	5	1.3	0.6	0	0	0	3.1	1.5	22.0
	NW	11	3	Reefs	5	0.6	0.2	0	0	0	1.1	1.0	15.3
												Geographic Rating:	**364.0**
Hickam (US)	N	41	2	> 1000	32	3.6	1.7	0.4	0	0	11.6	2.3	147.1
	NE	20	2	> 1000	32	14.6	19.1	6.9	0.6	0	127.4	5.2	332.7
	E	28	2	> 1000	32	8.1	10.2	3.9	0.4	0	70.6	4.3	272.1
	SE	4.1	4	295	16	1.6	1.3	0.2	0	0	7.0	1.9	124.2
	S	1.6	6	> 1000	32	2.2	1.1	0.2	0	0	6.6	1.9	364.0
	SW	1.5	6	> 1000	32	1.9	1.0	0.2	0	0	5.9	1.8	350.5
	W	17	2	> 1000	32	1.3	0.5	0.2	0	0	3.8	1.6	100.8
	NW	40	2	> 1000	32	3.2	0.5	0.2	0	0	5.6	1.8	115.2
												Geographic Rating:	**1806.4**

(a) Calculation of Geographic Factor – US bases (continued)

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
MacDill (US)	NE	0.9	7	6.8	10	8.6	2.9	0.3	0	0	19.3	2.7	191.4
	E	1.6	6	7.7	10	8.2	2.1	0.2	0	0	15.7	2.6	153.0
	S	75	1	450	18	3.7	1.2	0.2	0	0	8.3	2.1	37.0
	SW	23	2	> 1000	32	4.0	1.4	0.2	0	0	9.9	2.2	139.4
	W	34	2	> 1000	32	3.5	0.7	0.2	0	0	6.8	1.9	122.7
	NW	39	2	260	16	5.5	1.6	0.2	0	0	11.8	2.3	74.1
												Geographic Rating:	**717.6**
North Island (B)	S	1.5	6	> 1000	32	2.8	0.8	0.2	0	0	6.2	1.9	357.0
	SW	4.3	4	> 1000	32	3.1	0.7	0	0	0	5.1	1.7	222.0
	W	3.9	4	> 1000	32	6.8	2.4	0.2	0	0	15.3	2.5	323.2
	NW	5.6	4	> 1000	32	8.3	3.8	0.2	0	0	21.1	2.8	360.7
												Geographic Rating:	**1262.9**
Travis* (B)	S	203	0.3	> 1000	32	8.4	3.8	0.5	0.1	0	23.5	2.9	28.1
	SW	69	1	> 1000	32	7.7	5.6	0.9	0.1	0	31.6	3.2	103.5
	W	90	1	> 1000	32	1.7	0.5	0.1	0	0	3.4	1.5	48.3
	NW	233	0.3	> 1000	32	3.8	2.1	0.5	0.1	0	13.8	2.4	23.4
												Geographic Rating:	**203.3**

* Sacramento wind data [7] (51 km from Travis AFB).

(a) Calculation of Geographic Factor – US bases (continued)

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones — Wind Speed Zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						1	**2**	**3**	**4**	**5**			
Wake (B)	N	1.5	6	Reefs	5	1.1	1.2	0.5	0	0	8.1	2.0	61.0
	NE	0.7	8	Reefs	5	6.5	13.7	6.1	1.5	0.1	107.6	4.9	196.3
	E	0.5	8	Reefs	5	13.7	22.4	7.4	1.3	0.1	147.5	5.5	218.5
	SE	0.6	8	Reefs	5	4.6	2.7	0.4	0	0	15.5	2.5	101.5
	S	1.2	7	Reefs	5	1.5	0.9	0.2	0	0	5.4	1.8	62.1
	SW	1.2	7	Reefs	5	0.6	0.4	0.2	0	0	2.7	1.4	49.1
	W	3.0	4	Reefs	5	0.4	0.3	0	0	0	1.2	1.1	21.0
	NW	6.4	4	Reefs	5	0.4	0.3	0	0	0	1.1	1.0	20.7
												Geographic Rating:	**730.0**

(a) Calculation of Geographic Factor – Asian bases

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones — Wind Speed Zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						1	2	3	4	5			
Brunei Int'l (B)	N	5.4	4	> 1000	32	5.4	0.9	0	0	0	8.1	2.0	260.7
	NE	13	3	35	12	2.9	1.1	0	0	0	6.2	1.9	66.8
	E	11	3	19	12	0.5	0.1	0	0	0	0.6	0.8	30.3
	SE	14	3	6	10	0.2	0	0	0	0	0.2	0.6	17.4
	S	992	0.1	450	18	1.1	0.3	0	0	0	1.9	1.2	2.2
	SW	893	0.1	362	18	2.1	0.8	0	0	0	4.4	1.7	3.0
	W	11	3	> 1000	32	1.6	0.4	0	0	0	2.8	1.4	135.4
	NW	5.4	4	960	26	3.0	0.4	0	0	0	4.0	1.6	166.6
												Geographic Rating:	**682.3**
Butterworth (B)	N	248	0.3	635	26	0.7	0.2	0	0	0	1.3	1.1	8.5
	NE	196	0.5	509	18	0.9	0.2	0	0	0	1.5	1.1	10.2
	E	290	0.3	> 1000	32	0.4	0.1	0	0	0	0.5	0.8	7.6
	SE	610	0.1	> 1000	32	0.2	0	0	0	0	0.2	0.5	1.7
	S	48	2	305	18	1.0	0.2	0	0	0	1.6	1.2	42.2
	SW	1.4	6	5.6	10	2.0	0.5	0	0	0	3.5	1.5	91.9
	W	1.0	7	9.4	10	2.1	0.4	0	0	0	3.3	1.5	104.5
	NW	1.5	6	165	16	5.0	1.1	0	0	0	8.2	2.0	195.9
												Geographic Rating:	**462.5**

(a) Calculation of Geographic Factor – Asian bases (continued)

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
Denpasar (B)	N	75	1	454	18	0.3	0.1	0	0	0	0.4	0.7	13.2
	NE	68	1	630	26	0.1	0	0	0	0	0.1	0.5	11.9
	E	48	2	50	14	12.3	4.3	0.2	0	0	26.6	3.1	85.4
	SE	9.8	3	> 1000	32	9.9	3.8	0.2	0	0	22.7	2.9	277.5
	S	11	3	> 1000	32	1.3	0.2	0	0	0	1.9	1.2	119.4
	SW	13	3	> 1000	32	2.0	0.8	0.1	0	0	4.6	1.7	161.3
	W	1.1	7	62	14	5.3	2.5	0.5	0	0	16.0	2.6	251.3
	NW	1.1	7	45	14	0.9	0.3	0	0	0	1.8	1.2	119.7
												Geographic Rating:	**1039.6**
Jakarta Int'l (B)	N	12	3	321	18	3.2	0.5	0	0	0	4.6	1.7	90.4
	NE	9.1	3	518	18	2.2	0.4	0	0	0	3.4	1.5	81.5
	E	89	1	> 1000	32	2.1	0.5	0	0	0	3.5	1.5	48.8
	SE	267	0.3	> 1000	32	0.7	0	0	0	0	0.7	0.9	8.3
	S	143	0.5	> 1000	32	1.2	0.2	0	0	0	1.6	1.2	18.8
	SW	106	0.5	> 1000	32	1.8	0.4	0	0	0	2.8	1.4	22.7
	W	87	1	> 1000	32	2.9	0.8	0.1	0	0	6.0	1.8	58.9
	NW	17	2	111	16	2.0	0.4	0	0	0	3.2	1.5	47.5
												Geographic Rating:	**376.9**

(a) Calculation of Geographic Factor – Asian bases (continued)

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones — Wind Speed Zones 1	2	3	4	5	Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
Kuantan (B)	N	163	0.5	601	26	4.0	0.6	0	0	0	5.8	1.8	23.6
	NE	34	2	> 1000	32	2.7	1.0	0	0	0	5.5	1.8	114.3
	E	14	3	523	18	4.2	1.0	0	0	0	7.1	1.9	104.9
	SE	42	2	106	16	1.1	0.1	0	0	0	1.4	1.1	35.4
	S	237	0.3	103	16	1.7	0.2	0	0	0	2.3	1.3	6.4
	SW	208	0.3	61	14	3.1	0.7	0	0	0	5.2	1.8	7.3
	W	258	0.3	237	16	0.8	0.2	0	0	0	1.4	1.1	5.4
	NW	773	0.1	> 1000	32	0.9	0.2	0	0	0	1.5	1.1	3.6
												Geographic Rating:	**300.9**
Paya Lebar (B)	N	112	1	880	26	2.0	0.8	0	0	0	4.3	1.6	42.5
	NE	51	2	> 1000	32	4.1	1.5	0	0	0	8.6	2.1	133.0
	E	43	2	535	18	1.2	0.3	0	0	0	2.0	1.3	45.2
	SE	106	1	> 1000	32	0.6	0.1	0	0	0	0.8	0.9	29.0
	S	67	1	193	16	1.6	0.2	0	0	0	2.2	1.3	20.8
	SW	24	2	42	14	1.7	0.4	0	0	0	2.8	1.4	39.5
	W	52	2	103	16	1.3	0.4	0	0	0	2.5	1.4	43.4
	NW	521	0.1	> 1000	32	0.3	0.1	0	0	0	0.5	0.8	2.4
												Geographic Rating:	**355.8**

(a) Calculation of Geographic Factor – Canadian base

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
Bagotville (B)	E	116	1	40	12	7.1	6.3	1.5	0.2	0	38.3	3.5	41.4
	SE	511	0.1	60	14	1.0	0.6	0.1	0	0	3.3	1.5	2.1
	S	755	0.1	> 1000	32	0.5	0.2	0	0	0	1.1	1.0	3.3
	NW	922	0.1	> 1000	32	2.6	2.7	0.9	0.3	0.1	20.1	2.8	8.9
												Geographic Rating:	**55.7**

(a) Calculation of Geographic Factor – New Zealand base

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
Ohakea (B)	N	457	0.1	> 1000	32	5.7	1.7	0.2	0.1	0	12.6	2.4	7.6
	NE	363	0.1	> 1000	32	3.3	0.4	0	0	0	4.3	1.6	5.3
	E	121	0.5	> 1000	32	3.6	3.2	1.2	0.4	0.1	26.1	3.0	48.5
	SE	104	1	> 1000	32	2.0	3.3	1.8	0.8	0.2	35.5	3.4	107.7
	S	153	0.5	> 1000	32	0.8	0.6	0.2	0.1	0	4.7	1.7	27.1
	SW	19	2	111	16	1.6	1.1	0.4	0.2	0	9.0	2.1	67.4
	W	15	3	> 1000	32	3.3	5.2	2.9	1.9	0.4	66.6	4.2	400.1
	NW	173	0.5	> 1000	32	4.8	6.2	2.8	1.8	0.4	68.9	4.2	67.5
												Geographic Rating:	**731.2**

(a) Calculation of Geographic Factor – Middle East bases

Base or Airport	Wind Dir.	Dist. From Coast (km)	Dist. Rating (DR)	Fetch (km)	Fetch Rating (FR)	Wind Data % of time in wind speed zones					Wind Aggr. (WA)	Power WA	Geog. Factor (GF)
						Wind Speed Zones							
						1	2	3	4	5			
Al Udeid* (B)	N	111	1	205	16	5.9	7.8	3.2	0.9	0.1	62.3	4.1	65.2
	NE	28	2	227	16	4.2	2.5	0.3	0.1	0	14.0	2.5	78.5
	E	30	2	354	18	5.3	2.0	0.2	0	0	12.2	2.3	84.3
	SE	34	2	124	16	2.5	1.7	0.2	0	0	8.8	2.1	67.0
	S	970	0.1	> 1000	32	0.9	0.6	0.1	0	0	2.9	1.4	4.6
	NW	80	1	81	14	7.5	7.2	1.8	0.4	0.1	46.2	3.7	51.5
												Geographic Rating:	**351.1**
Camp Snoopy (B)	N	17	2	29	12	5.9	7.8	3.2	0.9	0.1	62.3	4.1	97.8
	NE	6.4	4	235	16	4.2	2.5	0.3	0.1	0	14.0	2.5	157.0
	E	6.5	4	366	18	5.3	2.0	0.2	0	0	12.2	2.3	168.5
	SE	8.4	3	135	16	2.5	1.7	0.2	0	0	8.8	2.1	100.6
	S	38	2	55	14	0.9	0.6	0.1	0	0	2.9	1.4	40.2
	NW	83	1	49	14	7.5	7.2	1.8	0.4	0.1	46.2	3.7	51.5
												Geographic Rating:	**615.6**

* Camp Snoopy wind data [7] (29 km from Al Udeid).

(a) Calculation of Geographic Factor – Australian bases

Base or Airport	**Wind Dir.**	**Dist. From Coast (km)**	**Dist. Rating (DR)**	**Fetch (km)**	**Fetch Rating (FR)**	**Wind Data % of time in wind speed zones**					**Wind Aggr. (WA)**	**Power WA**	**Geog. Factor (GF)**
						Wind Speed Zones							
						1	**2**	**3**	**4**	**5**			
Christmas Is.* (B)	N	3.9	4	Reefs	5						2.0	1.3	25.4
	NE	2.6	5	Reefs	5						4.7	1.7	42.2
	E	2.0	5	Reefs	5						83.1	4.5	112.4
	SE	3.1	4	Reefs	5						131.1	5.3	105.0
	S	3.9	4	Reefs	5						10.9	2.3	45.0
	SW	10	3	Reefs	5						1.2	1.1	16.0
	W	15	2	Reefs	5						1.0	1.0	10.1
	NW	3.7	4	Reefs	5						1.0	1.0	19.6
												Geographic Rating:	**375.6**
Cocos Is. (B)	N	3.6	4	Reefs	5	0.5	0.4	0.2	0	0	3.1	1.5	29.4
	NE	0.5	8	9.9	10	1.2	1.1	0.3	0.1	0	7.2	2.0	156.2
	E	0.6	8	9.4	10	5.7	13.4	8.3	2.0	0.2	127.9	5.2	416.3
	SE	3.0	4	Reefs	5	7.9	21.3	12.8	3.5	0.2	201.7	6.1	121.5
	S	0.3	8	Reefs	5	2.1	2.4	0.9	0.2	0	16.7	2.6	104.2
	SW	0.2	9	Reefs	5	0.4	0.3	0.1	0	0	1.9	1.2	55.5
	W	0.3	9	Reefs	5	0.3	0.2	0.1	0	0	1.6	1.2	52.8
	NW	1.8	6	Reefs	5	0.2	0.3	0.1	0	0	1.5	1.1	34.0
												Geographic Rating:	**969.9**

* 0.65*Cocos Is. wind aggregates [22].

(b) ModGCIA and CLIMAT prediction data

Base or Airport	Location	Ave. Temp. (°C)	Ave. Rel. Humidity (%RH)	Calculated TOW (h)	Power TOW x 10^{-6}	Geographic Rating (GR)	ModGCIA x 10^{-9}	Predicted CLIMAT (%)
Diego Garcia	Indian ocean	27.5	80.0	5492	283.0	398.8	112.8	4.31
Elmendorf	US - Alaska	1.9	68.9	1900	25.7	51.7	1.3	0.05
Guam	Pacific ocean	26.2	72.7	3898	137.4	364.0	50.0	1.91
Hickam	US - Hawaii	24.9	69.3	3343	92.1	1806.4	166.4	6.36
MacDill	US - Florida	23.0	70.8	3593	108.4	717.6	77.8	2.97
North Island	US - California	17.3	71.9	3667	113.6	1262.9	143.4	5.48
Travis*	US - California	15.6	66.0	2616	53.0	203.3	10.8	0.41
Wake	Pacific ocean	26.9	75.2	4492	179.7	730.0	131.2	5.01
Brunei Int'l	Asia - Brunei	27.6	84.9	6511	415.8	682.3	283.7	10.84
Butterworth	Asia - Malaysia	27.4	78.2	5114	240.8	462.5	111.4	4.26
Denpasar	Asia - Indonesia	27.6	78.6	5199	250.0	1039.6	259.9	9.93
Jakarta Int'l	Asia - Indonesia	27.4	79.9	5470	280.5	376.9	105.7	4.04
Kuantan	Asia - Malaysia	26.9	85.7	6664	438.2	300.9	131.9	5.04
Paya Lebar	Asia - Singapore	27.3	85.8	6689	442.0	355.8	157.3	6.01
Bagotville	Canada - Quebec	2.5	74.3	2598	52.1	55.7	2.9	0.11
Ohakea	New Zealand – Nth. Is.	13.4	79.4	4870	215.7	731.2	157.7	6.02
Al Udeid**	Middle East - Qatar	29.2	51.8	1063	6.9	351.1	2.4	0.09
Camp Snoopy	Middle East - Qatar	27.3	57.6	1631	18.2	615.6	11.2	0.43
Christmas Is.***	Indian ocean	25.1	78.6	5170	246.8	375.6	92.7	3.54
Cocos Is.***	Indian ocean	26.8	76.9	4838	212.5	969.9	206.1	7.87

* Suisan City climate data [27] (9 km from Travis AFB)

** Climate data [25].

*** Climate data [22].

Appendix G: Data for Predicted Sites > 200 km from Coast

Base or Airport	Location	Distance from Coast (km)	Average Temp. (°C)	Average Relative Humidity (%)	Calculated TOW (h)	TOW $^{0.49}$/Dist. from Coast (h $^{0.49}$/km)	Predicted CLIMAT (%)
Eielson	US - Alaska	418	-3.4	64.1	905	0.07	0.12
Nellis	US - Nevada	389	19.6	30.7	143	0.03	0.05
Cold Lake	Canada - Alberta	1085	1.7	69.8	1967	0.04	0.07
Mirabel/Montreal	Canada - Quebec	378	6.4	71.0	2738	0.13	0.23
Khorat*	Asia - Thailand	204	27.0	70.0	3486	0.27	0.48

* Nakhon Ratchasima climate data [27] (5 km from Khorat).

<table>
<tr><td colspan="3">DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA</td><td colspan="2">1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)</td></tr>
<tr><td colspan="3">2. TITLE

Modification of the Geographic Corrosivity Index and its Application to Overseas Bases</td><td colspan="2">3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)

Document (U)
Title (U)
Abstract (U)</td></tr>
<tr><td colspan="3">4. AUTHOR(S)

J.C.Bitcon and S.G.Russo</td><td colspan="2">5. CORPORATE AUTHOR

DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend Victoria 3207 Australia</td></tr>
<tr><td>6a. DSTO NUMBER
DSTO-TR-2109</td><td>6b. AR NUMBER
AR-014-150</td><td>6c. TYPE OF REPORT
Technical Report</td><td colspan="2">7. DOCUMENT DATE
March 2008</td></tr>
<tr><td>8. FILE NUMBER
2007/1118807/1</td><td>9. TASK NUMBER
AIR 05/048</td><td>10. TASK SPONSOR
TFSPO</td><td>11. NO. OF PAGES
55</td><td>12. NO. OF REFERENCES
27</td></tr>
<tr><td colspan="3">13. URL on the World Wide Web

http://www.dsto.defence.gov.au/corporate/reports/DSTO-TR-2109.pdf</td><td colspan="2">14. RELEASE AUTHORITY

Chief, Maritime Platforms Division</td></tr>
<tr><td colspan="5">15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111</td></tr>
<tr><td colspan="5">16. DELIBERATE ANNOUNCEMENT

No Limitations</td></tr>
<tr><td colspan="5">17. CITATION IN OTHER DOCUMENTS Yes</td></tr>
<tr><td colspan="5">18. DSTO RESEARCH LIBRARY THESAURUS http://web-vic.dsto.defence.gov.au/workareas/library/resources/dsto_thesaurus.htm

Aluminium, Aircraft, Algorithm, Atmospheric corrosion, Environmental factors</td></tr>
<tr><td colspan="5">19. ABSTRACT
A Geographic Corrosivity Index (GCI) has been developed previously that models the atmospheric corrosivity at RAAF bases within Australia. Geographic, wind and other climate data are used to calculate the index for each base. The correlation of the GCI with atmospheric corrosion data from a large number of overseas bases, covering a broader range of geographic features and climatic conditions than experienced in Australia, was investigated to test its wider application. Modifications have been made to the GCI that enable it to be used with greater confidence for bases around the world that are within 200 km of the coast. Bases greater than 200 km from the coast have low corrosion rates, and a simpler algorithm based on time of wetness and distance from the coast was used to predict atmospheric corrosivity at these inland bases.</td></tr>
</table>